

9-1-2008

An evaluation of energy consumption and emissions from intermodal freight operations on the eastern seaboard: A GIS network analysis approach

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*An Evaluation of Energy Consumption and Emissions from Intermodal Freight Operations
on the Eastern Seaboard: A GIS Network Analysis Approach*

**Master of Science in Science, Technology, and Public Policy Thesis Submitted in
Fulfillment of the Graduation Requirements for the
College of Liberal Arts/Public Policy Program at
ROCHESTER INSTITUTE OF TECHNOLOGY
Rochester, New York
September 2008**

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1. Abstract

As global trade continues to increase, the energy and environmental impacts of freight movement in the US have become more of a concern. As such, the freight transport system needs to consider opportunities to meet customer objectives, while also meeting social goals. In the US there has been legislation enacted to address the growing impact that freight movement has on the environment, but there are limited tools to assist in the implementation of those policies. This research sets forth a process for creating a geospatial intermodal freight transportation (GIFT) model within ArcGIS that can be used to analyze freight movement under different economic and environmental scenarios.

The GIFT model uses an intermodal network that connects various modes (rail, truck, and ship) via intermodal terminals. ArcGIS Network Analyst is used to create the intermodal network and conduct optimal route analysis for various network attributes. Routes along the network are characterized not only by temporal and distance attributes, but also by cost, energy, and emissions attributes. Decision makers can use the model to explore tradeoffs among alternative route selection across different modal combinations, and to identify optimal routes for objectives that feature energy and environmental parameters (e.g., least carbon dioxide intensive route). The research illustrates the use of this network using a case study that analyzes freight traffic along the US Eastern Seaboard.

2. Introduction

The movement of goods is an essential component of modern societies. Increases in mobility, for both persons and goods, have led to economic prosperity. The purpose of a transport system is to overcome physical constraints in a timely and efficient manner. During the 20th century, trade went from being local in scale to global and therefore the transport systems carrying goods became a global network. In order to be competitive in the current global market, the US has had to build a more robust transport system. If the US economy continues to grow at an annual rate between 2.5 and 3.0 percent over the next 20 years, domestic freight tonnage will double and the volume of freight moving through the largest international gateways could triple or quadruple (Cambridge Systematics, 2005). As technology has advanced, the ability to overcome physical barriers and time constraints has become much easier, but this has come at a cost.¹ The result of the increases in freight movement has been an increase in energy consumption, pollution emissions, and congestion throughout the freight transport network in the US, factors that impact environmental, ecological and human health. Ultimately, a collaborative system of the different modes of freight movement would create a more sustainable freight network that would also be more environmentally accountable and efficient.

The increases in the amount of freight movement in the US can be attributed to multiple factors. The most obvious factor is the increase in US population during the 20th century. In 1998, over 15 billion tons of goods were moved in the US, translating into 310 pounds of freight moved daily for each US resident (Sedor and Caldwell, 2002). Not only is there an increasing demand in goods to be moved, there is also a growing need to have goods delivered more quickly. During the past decade there was another influence on freight known as just-in-time delivery and this has been coupled with the concept of door-to-door delivery (Rodrigue, Slack, and Comtois, 2001). Just-in-time delivery is defined as being the arrival of goods, as needed, for production or consumption. The practice of just-in-time delivery minimizes the need for warehousing and maintenance of large inventories, and facilitates the growth of door-to-door transport. A major concern of just-in-time service is that in order to maintain low inventories there is a need for

¹ For the duration of this thesis, the term “cost” refers to the energy consumption, environmental impact, and economic cost of freight transportation unless otherwise noted.

shipments to arrive more frequently and expeditiously. Often, this requires the use of trucks to move freight from origin to destination.

The door-to-door delivery service has been enhanced by the growth of the e-commerce market. By 2003, the business to consumer transactions are expected to have grown over 10 times its 1998 level of \$8 billion to nearly \$100 billion (Rodrigue et al., 2001). The door-to-door service and e-commerce have brought business to companies such as Federal Express and the United Parcel Service (UPS), who specialize in door-to-door service. A major disadvantage of this service is that instead of having one truck carrying a large volume, there are many smaller trucks carrying smaller volumes. The net result is an increase in the energy consumption and emissions from freight transport. Although the cost of transporting freight dropped from 16.1 percent of US gross domestic product (GDP) in 1980 to 10 percent in 2000 (Sedor and Caldwell, 2002), the externalities of freight transport in the United States have increased, and the accountability for externalities have decreased.

The increase in the amount of goods being moved and the changes in the delivery services has affected air emissions. There are numerous pollution problems associated with freight transportation (Ang-Olson and Cowart, 2002; Bickel, 2001; Facanha and Horvath, 2005; Kroon, 1991). Problems include the release of local and regional pollutants, such as carbon monoxide (CO), nitrogen dioxide (NO_x), sulfur dioxide (SO_x), and coarse particulate matter (PM₁₀), as well as greenhouse gasses such as CO₂. Each of the pollutants contributes to a variety of environmental and health-related concerns.

Diesel PM is a carcinogen that can lead to cardiopulmonary problems in exposed populations. NO_x is an ozone precursor that leads to smog, which also presents health problems, such as asthma. CO is a poisonous gas that causes damage to the heart and central nervous system of exposed individuals. SO_x is a precursor to acid deposition that can lead to particulate formation causing breathing problems and possible permanent pulmonary damage. CO₂ is a greenhouse gas, which leads to global warming and climate change. Given the severity of the impacts of these pollutants, it is imperative that they be included when determining the environmental impact of freight movement in the US. The inclusion of air pollutants in freight transport models allow users to explore the tradeoffs associated with different policies and technologies.

Recently, freight transport has been looked at more critically as the emissions from freight traffic, fuel consumption, and congestion issues have become more of a concern for the US and abroad (Kreutzberger, Macharis, Vereecken, and Woxenius, 2003; Lakshmanan and Han, 1997; Marcotullio, Williams, and Marshall, 2005). As more trucks are being utilized to move freight, congestion on US highways continues to increase on previously congested arterials and secondary arterials. The air quality of many of the congested corridors is a growing concern for many residents and businesses in and around heavily travelled freight arterials. Highways are not the only areas of concern, ports and freight terminals also share the same problem. As more freight is imported to the US, major freight centers such as Los Angeles, Houston, and Jacksonville continue to encounter issues with air pollution, as well as noise pollution.

While the freight transport scenario may seem bleak, the role of logistics has become a critical component to improving freight transport in the US (Rodrigue et al., 2001). One way to address the impacts of freight movement is through the careful consideration of routes along an intermodal freight system (Owens and Lewis, 2002). The second half of the 20th century gave birth to an innovative concept known as intermodal transport. Although a number of definitions for “intermodal freight transport” exist (Bontekoning, Macharis, and Trip, 2004), this thesis defines intermodal freight transport as “the movement of goods in one and the same loading unit or vehicle which uses successive, various modes of transport (rail, truck, and ship) without any handling of the goods themselves during transfers between modes (European Conference of Ministers of Transport, Eurostat, and UNECE, 1997; Macharis and Bontekoning, 2004).

The goal of intermodalism is to be able to utilize the most cost-efficient modes of transport to move freight from its origin to its destination (Lowe, 2005). Route selection based on environmental or energy criteria, as opposed to the traditional criteria of cost and time-of-delivery, could help identify energy- and environmentally-sustainable ways to move freight throughout the US and abroad, since the environmental impact of freight is becoming more widely noticed (Ang-Olson and Cowart, 2002; Facanha and Horvath, 2005; Hricko, 2006; Kreutzberger et al., 2003; Leonardi and Baumgartner, 2004).

The intermodal system is much more complex than unimodal or bimodal systems. From a stakeholder perspective, the system includes shippers, receivers, drayage operators, terminal

operators, network operators, and intermodal operators (Macharis and Bontekoning, 2004). Geographically, the network includes nodes representing origins, destinations, and intermodal terminals, and arcs linking these nodes on road, rail, air, or water (Janic, 2007). From an operational perspective, the system includes trucks, trains, planes, ships, and the host of equipment that allows intermodal terminals to operate effectively. Each of the arcs in the intermodal network, along with the necessary equipment, has their own costs which contribute to the overall impact of freight movement.

In short, to understand intermodal freight transport is to understand a complex web of people, places, and technologies that are intertwined in a network constructed to deliver goods throughout the country, and the world, in the most efficient and timely way possible. There have been three pieces of legislation that have attempted to encourage the use of intermodalism for freight movement in the United States, but given the complex nature of the system, and a lack of comprehensive analytical tools, little progress has been made.

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 (Public Law 102-240) was one of the first pieces of legislation in the post-interstate highway system era to set forth an intermodal approach to both passenger and freight transportation. ISTEA presented the need for a comprehensive planning effort at the state, local, and metropolitan levels. The bill placed significant emphasis on obtaining stakeholder support in the planning of comprehensive approaches to both passenger and freight transportation. Although the legislation set out with the best of intentions, the goals proved to be difficult to achieve, given the fragmentation and culture of the freight transportation sector.

ISTEA expired in 1997 and was followed by the Transportation Equity Act for the 21st Century (TEA-21) (Public Law 105-178), which was enacted in June 1998. TEA-21 focused heavily on improving safety, protecting the environment, and improving access to public transportation. TEA-21 also set forth a more detailed list of objectives to be included in regional transportation plans. This list included a stipulation that all transportation plans place emphasis on protecting and enhancing the environment, promoting energy conservation and efficiency and working to improve the connectivity of the transportation system across the different modes for both passengers and freight. The legislation stressed the importance of safety by focusing on seat belt

usage and tighter restrictions on drunk driving. While the goals of the legislation set out to improve the connectivity of the freight transport system and increase energy efficiency and environmental protection, TEA-21 failed to evoke implementable policies to address the issues of freight movement in the US adequately.

With the expiration of TEA-21 in 2003, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) was signed in August 2005 and is enforced through 2010. The bill contains a variety of measures to improve and maintain transportation infrastructure in the US, focusing mainly on the repair and maintenance of highways and interstate systems. The legislation quickly lost the support of the public when it was discovered that the bill contained over six thousand earmarks, including the infamous “bridge to nowhere” project in Alaska. More attention has been paid to the freight transport system, but a majority of the focus has been on construction and improvements of the Federal highway system.

Although the three pieces of legislation (ISTEA, TEA-21, and SAFETEA-LU) set out to improve the efficiency of the transportation system, they ended up placing a majority of their focus on highways, interstates, and passenger mobility with very little emphasis on freight movement. The movement of freight in the US is a major concern that needs to be addressed, chiefly because of the adverse affects freight movement has on our environment. The amount of freight being shipped is increasing and most freight is being shipped using trucks traveling on the US interstate and highway systems. The increase in freight traffic has caused large amounts of congestion, increased petroleum usage, increases in the release of greenhouse gasses (GHGs), and time delays which impact various components (e.g. cost) of the entire supply chain (Cambridge Systematics, 2005; T. Golob and Regan, 2001; Komor, 1995; National Ports and Waterways Institute, 2004; Vanek and Morlok, 2000).

A recent report by the Government Accountability Office (GAO) highlights the challenges that freight mobility in the US presents (U.S. Government Accountability Office, 2008). The past policies have placed a large amount of responsibility on the local municipalities to plan, construct, and provide funding for freight transportation projects. As noted in a prior GAO report, providing funds to states and expecting states to make investment decisions has proven to place a large bias on passenger-oriented projects (U.S. Government Accountability Office,

2007). State and local officials are apt to provide funding for passenger-related projects because passengers vote and freight containers do not, and the objective is to maximize their investment. A second major issue involves the fragmentation of the intermodal transport system. Separate agencies are provided funding and have individual missions, but in order for intermodal transport to work, the individual agencies, their missions, and their funding need to be combined in order to achieve a suitable intermodal network.

A disconnect exists between the introduction of policy and the implementation of policy. A primary reason for the lack of connection between policy introduction and policy implementation is that those responsible for policy implementation represent only sub-elements of the entire system. Administrations and agencies responsible for implementation are focused on the sub-element that they are liable for and therefore fail to fulfill the needs of the entire system. There are a large number of decision points encountered during policy implementation and, as noted largely during the 1980s and 1990s, gridlock can take place in which different institutions block each other from carrying forth their objectives (Peters, 2004). Peters notes the importance of decision makers at the bottom of the organization in determining effective policies (2004). In order for more efficient freight policy, the administrators responsible for each of the sub-elements of the freight system need to cooperate in order to implement comprehensive freight policy.

Typically, models are used to assist with the visualization and optimization of certain events, in particular those events relating to the environment. Models can be used to assist in eliminating bias. A model also allows for the ability to conduct a sensitivity analysis to understand the robustness of a decision and investigate alternative scenarios, which allows users to obtain results based on different states of nature. These activities are greatly beneficial to policymakers because they can assist in not only creating policy, but in understanding the possible effects that policies have.

The use of Geographic Information Systems (GIS) as a modeling tool in transportation emerged during the late 1980s. Since that time, great advances have been made and GIS has become a key technology in the transportation sector. The ability to combine data management, manipulation, and analysis into one platform has been of great benefit to those in the area of

transportation. The use of GIS in transportation has allowed analysts to combine and demonstrate the interdependence between the natural, social, and economic systems (Thill, 2000). GIS also provides the capability to construct network models constructed with arcs and nodes to simulate movement over a given geography.

Currently there are models that analyze freight flows within an intermodal network. Some of these models use complex transportation algorithms with high-end, self designed software, while others use more common geographic software such as TransCAD or ArcGIS. A major issue with many of the models is that they fail to address the impacts that freight has on the environment and they fail to adequately address the connectivity of an intermodal freight network. The current tools often used to address economic issues, such as least cost routing, are based on the need for just-in-time delivery. Current models fail to allow a user to determine a route that minimizes CO₂ as well as determine the least cost route in order to measure the trade-offs associated with each route within an intermodal network.

Network optimization models are an important tool for evaluating freight transport logistics (Crainic, 2002). The two important types of network optimization models are: (1) trans-shipment models; and, (2) shortest path models. Model choice depends on the problem being studied. In trans-shipment models, macro-level supply and demand for commodities are identified (usually exogenously). The network models are used to determine how to meet demand, at least cost, given constraints on supply and delivery mechanisms. An example of this type of modeling would be a manufacturer looking to find the least-cost route to distribute goods from several production facilities to a number of distribution outlets throughout the country.

Integrated into these models would be shortest-path algorithms, such as the Dijkstra algorithm, to ensure the model selects the distribution network that achieves least cost (Zhan, 1997). Researchers have used such models to better understand large-scale intermodal freight transport in the US (Southworth and Peterson, 2000; Luo and Grigalunas, 2002; Xu, Hancock et al., 2002). Each of the intermodal freight models set forth by the researchers are unique in that they include the costs (penalties) associated with intermodal terminal operations, as discussed in detail by others (Ziliaskopoulos and Wardell, 2000).

The integration of intermodal modeling approaches with Geographic Information Systems (GIS) is a relatively new concept. For example, researchers have applied a GIS based system (TransCAD) with linear programming software such as the General Algebraic Modeling System (GAMS) to conduct shortest-path analysis of intermodal freight movement (Boile, 2000). Standifer and Walton (2000) and Southworth (2000) integrated highway, rail, and marine networks in an intermodal GIS environment to study freight transport. Finally, recent work by the US Bureau of Transportation Statistics utilized shortest path algorithms in a GIS environment to validate travel distances for freight movement in the US (Lewis, 2007). Although prior intermodal modeling work has taken place, the models fail to capture the externalities of freight transport accurately and allow a user to determine optimal routes based on environmental attributes.

Similar to prior modeling, the Geospatial Intermodal Freight Transport (GIFT) model integrates the highway, waterway, and rail networks into one holistic network to be used with the Network Analyst extension within ArcGIS, the GIS software from the Environmental Systems Research Institute (ESRI). The model was also equipped with a user interface, allowing a user to input emissions, speeds, and transfer times that are used to calculate a route for the user. With these enhancements, the GIFT model allows for a decision maker to assess the trade-offs associated with different routes (e.g. least time vs. least CO₂) and determine policy alternatives to make freight movement more efficient.

In the future, policymakers and planners will look to operational strategies to reduce overall pollution by changing how trucks, trains, and ships operate (Ang-Olson and Schroeer, 2002). Examples of such methods include reduced highway speeds; improved freight logistics; restricting engine idling time; and utilizing new technologies and fuels, to name a few (Komor, 1995). Also, reducing freight emissions can be achieved by shifting from higher to lower pollution-intensive modes (such as from trucks to rail) (Nijkamp, Reggiani, and Bolis, 1997). The GIFT model assists policymakers and planners in assessing the applicability of various freight transport strategies.

The purpose of this thesis is to apply a geospatial model to evaluate tradeoffs among various policy goals associated with goods movement in the US. The thesis develops and applies an

ArcGIS model (GIFT, mentioned above) to characterize routes along an integrated rail, highway, and waterway network to explore temporal, environmental, and economic attributes. Decision makers can use the model to explore tradeoffs among alternative route selections across different modal combinations, and to identify optimal routes for objectives that feature energy and environmental parameters (e.g., least carbon dioxide intensive route). The research illustrates the use of this network using a case study that analyzes freight traffic along the US Eastern Seaboard, and discusses policy implications of the results.

The next section of the thesis presents a literature review of goods movement in the US. That section is followed by a detailed summary of the methodology used to create the GIFT model and a discussion of three case studies that were conducted using the GIFT model. The thesis concludes with a discussion of policy implications.

3. Literature Review

The following outlines freight movement in the US, providing both a historical and future outlook, examining the externalities attributable to freight transport, and discussing prior intermodal modeling.

3.1 Freight Flow in the United States

The movement of freight is an activity that has taken place for thousands of years. Whether goods are moved by horse-drawn cart or by a large ocean-going vessel, the ability to move goods is a necessary activity that allows societies to function. The movement of goods is also an essential part of any economy. The ability to move raw materials to a manufacturer, and move a final product from the manufacturer to the consumer is commonly referred to as the supply chain. The supply chain can be defined as the set of all events that take place, from gathering of raw materials to the consumption of a good. Logistics plays a major role within the supply chain. Logistics is defined by the Council of Logistics Management as the part of the supply chain process that deals with the planning, implementation, and control of the efficient and effective flow and storage of goods, services, and related information from point of origin to point of consumption in order to meet customer requirements (Long, 2004).

Intermodal networks for the transportation of freight have been widely discussed both in the United States and abroad (Jong, Gunn, and Ben-Akiva, 2004; Plakhotnik, Onyshchenko, and Yaryshkina, 2005; Tsamboulas, Vrenken, and Lekka, 2007). With the onset of the industrial revolution during the 20th century, the movement of freight changed immensely. The need for raw materials to be transported brought about the introduction of new transportation technologies. The enhancement of rail and shipping vessels, coupled with improved logistics, helped to develop world port centers, which allowed for a considerable increase in the amount of goods that could be brought into one locale and then distributed out along different networks to their final destinations (Levinson, 2006). In the 21st century, transportation technology has improved, but the networks on which freight is transported is the same infrastructure that was first constructed in the early 20th century. Needless to say, the transport networks are congested and the infrastructure is growing older, less safe, and more costly, all while the cost to transport goods has decreased (Sedor and Caldwell, 2002).

Intermodalism has had a major impact on logistics. First, it has limited the number of terminals and shipping lines carrying cargo. Intermodal terminals are highly specialized and require high-tech equipment in order to compete in the intermodal freight market. Although the equipment may seem relatively basic, there are many standardized and technical components that make moving intermodal cargo more efficient. Typical containers are eight feet wide, and eight feet six inches high. The length of the container will vary between twenty and forty feet. Twenty foot containers are called a TEU, or twenty-foot equivalent unit. There are also forty foot containers known as an FEU, or forty foot equivalent unit. Often the forty-foot equivalent unit is just noted as two TEU's denoting two twenty foot equivalent units. The standard dry-freight twenty foot container has a gross weight of roughly 20,000 kilograms, while the forty foot container has a gross weight capacity of roughly 30,000 kilograms (Long, 2004). The smaller containers are used by shippers who might be moving higher priced cargo in smaller numbers. The forty foot container is often used by bulk shippers who may be looking to keep the cost down.

Moving freight among different modes of transport has been a practice that has existed for millennia. Frequently freight is moved from one mode to another. The railroad allowed freight

to be moved from horse carriages to trains and vice versa. Since that time there have been many advances in freight technology that allow for the seamless transfer of freight between road, rail, waterway, and air modes of transport. There has been considerable progress made in intermodalism in Europe. A catalyst for the increase in intermodal development has been the Channel Tunnel between the UK and France which opened in 1994 (Lowe, 2005). The tunnel saw a large increase in freight traffic using the drive-on/drive-off freight shuttle service (Lowe, 2005). As freight demands continued to change, the use of the Tunnel for intermodal freight became even more widespread. In the United States, progress in intermodal freight has been more gradual, but as the costs of fuel, congestion, and continued concern for global climate change continue to gain attention, a new approach to freight movement seems inevitable.

Intermodalism in the United States really came to the forefront during World War II as a way to address security concerns. Soon after its introduction, shippers and receivers began to discover other benefits that accompanied the benefit of security (Long, 2004). The other benefits included enhanced safety to cargo and workers and improved efficiency in moving cargo (Long, 2004). Given that intermodal freight is being moved in a container, there is an increase in security, since a container is more difficult to steal, and more importantly, disallows others from seeing the goods that are located inside. The counter to the security asset has arisen as recent criticism has targeted containers as being a detriment to national security because they allow for goods to be unknowingly brought into the country in secure containers.

The container provided a major logistics advantage because machines could move standardized containers, eliminating the need for individuals working on the loading/unloading docks. The advanced equipment promoted a safer work environment, although there was much in the way of criticism because machines took the jobs away from the individuals. Containers became standardized and were constructed with set dimensions. Standardization allowed for handling equipment to be more easily constructed to manage cargo. Containerization allowed for consolidation of smaller cargo into a large container, minimizing the amount of cargo that needed to be moved on a given vessel. These factors have helped in making intermodalism a more feasible option for freight transport (Levinson, 2006).

More important than the equipment used in an intermodal network, however, is the operational aspect of the system. Intermodalism requires a considerable amount of cooperation between different carriers of different types. Cooperation is achieved by the use of a system which is capable of transferring freight between road, rail, waterway, and air modes of transport (Lowe, 2005). Many have suggested that the best method to help promote change in the freight industry is to work to incorporate more rail and waterway freight movement into our current freight network by leveraging the resources that currently exist (Komor, 1995; National Ports and Waterways Institute, 2004; F. Southworth, and Bruce E. Peterson, 2000; Standifer and Walton, 2000; Vanek and Morlok, 2000). The goal of intermodalism is to be able to utilize the most cost-efficient use of modes of transport to move freight from its origin to its destination (Lowe, 2005). Intermodalism allows for the advantages of truck transport while at the same time offering more environmentally friendly aspects, such as less vibration, less noise, and less pollution.

There have been two major widespread events which have impacted intermodalism during the past fifty years. The first was the container revolution. In 1956, a crane lifted fifty-eight aluminum truck bodies aboard a tanker in Newark, New Jersey and from that point on our world was forever changed (Levinson, 2006). Simply put, the container made shipping less expensive and re-shaped the world economy. As opposed to moving a few thousand TEU's on an open water vessel it is now possible to move over 6,000 TEU's at a time. As technology continues to develop, that number is much closer to, if not exceeding, 10,000 TEU's per voyage. Ports need to be able to keep up with the continuing freight technology by increasing their freight carrying capacity in order to maximize economic potential. Given the current inability of the ports and intermodal facilities to keep up with current freight demand, much of the freight in the United States at some point during its journey is moved by truck.

Accompanying the container revolution was the application of the roll-on/roll-off ferry system (also known as RORO). This is in contrast to the lift-on/lift-off system (also known as LOLO). RORO can be used to move freight over both long and short distances. RORO utilizes wheeled freight, or freight loaded on chassis, to roll on to and off of a given vessel. This type of technology was used to primarily move automobiles and military equipment until the middle half of the 20th century, when merchants began using the RORO system to move raw materials and consumer goods. The LOLO system has become more noticeable at many ports and facilities

around the world and is often utilized for long distance freight movement. These systems use cranes to lift containers off of one mode and either place the containers directly onto another mode or place the container into a holding area until it is ready to be loaded onto another mode to complete its journey. The LOLO system requires a significant amount of equipment to perform and an enhanced logistics system to be able to inventory the stock of containers at the site. Given the perceived complexity of moving freight by ship, trucks are more often used as they are more logistically simple.

In the US, the most common form of freight movement is the truck. As the amount of freight being moved has dramatically increased over time, the amount of truck haulage has increased as well. Currently the modal share sways heavily towards truck freight with less use of rail and even less use of short sea shipping (National Ports and Waterways Institute, 2004; Office of Freight Management and Operations, 2006). The increase in truck traffic has increased air pollution, congestion, and even accident rates on major arterials. In 2002, roughly 1.6 billion tons of freight were moved domestically (Office of Freight Management and Operations, 2006). According to the most recent report released by the FHWA, by 2035 nearly 3.5 billion tons of international shipments will need to be distributed throughout the domestic transportation network (Office of Freight Management and Operations, 2006). Given the current infrastructure that is in place, moving this amount of freight will be difficult.

The shipment increase of over 100% will place pressure on an aging transportation infrastructure and place additional burden on local municipalities responsible for maintaining critical transportation infrastructure. The current transport infrastructure encounters difficulties in meeting the freight demand; furthermore the frail infrastructure has reduced the efficiency of the freight transport process at an alarming rate (U.S. Government Accountability Office, 2008). To make matters more challenging, the FHWA anticipates that of the preliminary 3.5 billion tons of freight, 2.1 billion tons will be moved using trucks (Office of Freight Management and Operations, 2006).

The shipping trends are likely to continue in the coming decades due to increasing international and domestic trade. For instance, the total vehicle miles traveled (VMT) for freight trucking is expected to increase from 230 billion VMT to 413 billion VMT between 2005 and 2030, an

annual increase of 2.3% (Office of Freight Management and Operations, 2006). The increase in VMT for freight traffic will be made worse by the increase expected in passenger traffic. The increases from both the freight and passenger sectors will create further congestion, causing increases in delays, energy consumption, and emissions from idling trucks. Likewise, rail freight transport is expected to increase from about 1,550 billion ton-miles (BTM) to 2,403 BTM (1.7%/yr) over the same period, while domestic marine freight is expected to increase from 650 BTM to 844 BTM (1.0%/yr) (Office of Freight Management and Operations, 2006). Most notably, air freight is expected to increase from about 29 BTM to almost 102 BTM (4.9%/yr) during this period (U.S. Energy Information Administration, 2007). It should be noted that concerns have been noted about the safety and reliability of the rail system (Congressional Budget Office, 2006).

With the large amount of truck traffic that will be traveling on our nation's highways and interstates, the congestion outlook becomes particularly startling. The I-95 Corridor, which stretches from the state of Maine through the state of Florida, is one of the most heavily traveled routes in the United States (National Ports and Waterways Institute, 2004). This Corridor contains a few of the country's largest metropolitan areas including Boston, New York City, Philadelphia, Baltimore, Washington DC, and Miami. With an increase in not only freight traffic but passenger traffic as well, this area has a growing congestion problem as well as an aging infrastructure problem. Figure 1, Figure 2, and Figure 3 display the pending congestion problems in the corridor between 1998, 2010, and 2020.

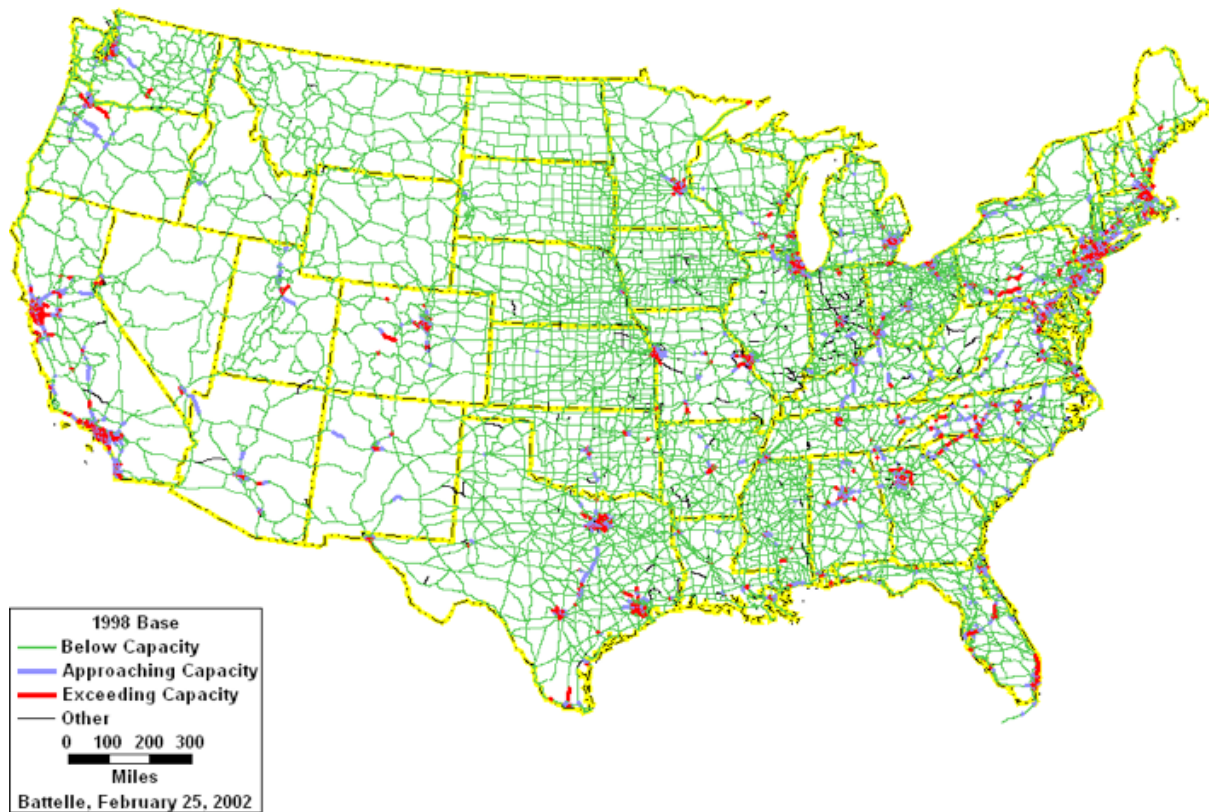


Figure 1. 1998 United States highway capacities

Figure 1 shows the highway capacities in the US in 1998. Two of the most congested areas in the country, during this time, were in California along the I-5 corridor, stretching from San Francisco, CA to San Diego, CA. The other heavily travelled corridor was the I-95 corridor on the east coast. As of 1998, significant travel stretched from Portland, ME to Washington, D.C.. Many other metropolitan areas experienced segments of highway exceeding capacity, but those two corridors stood out as having the most significant amount of travel at the time.

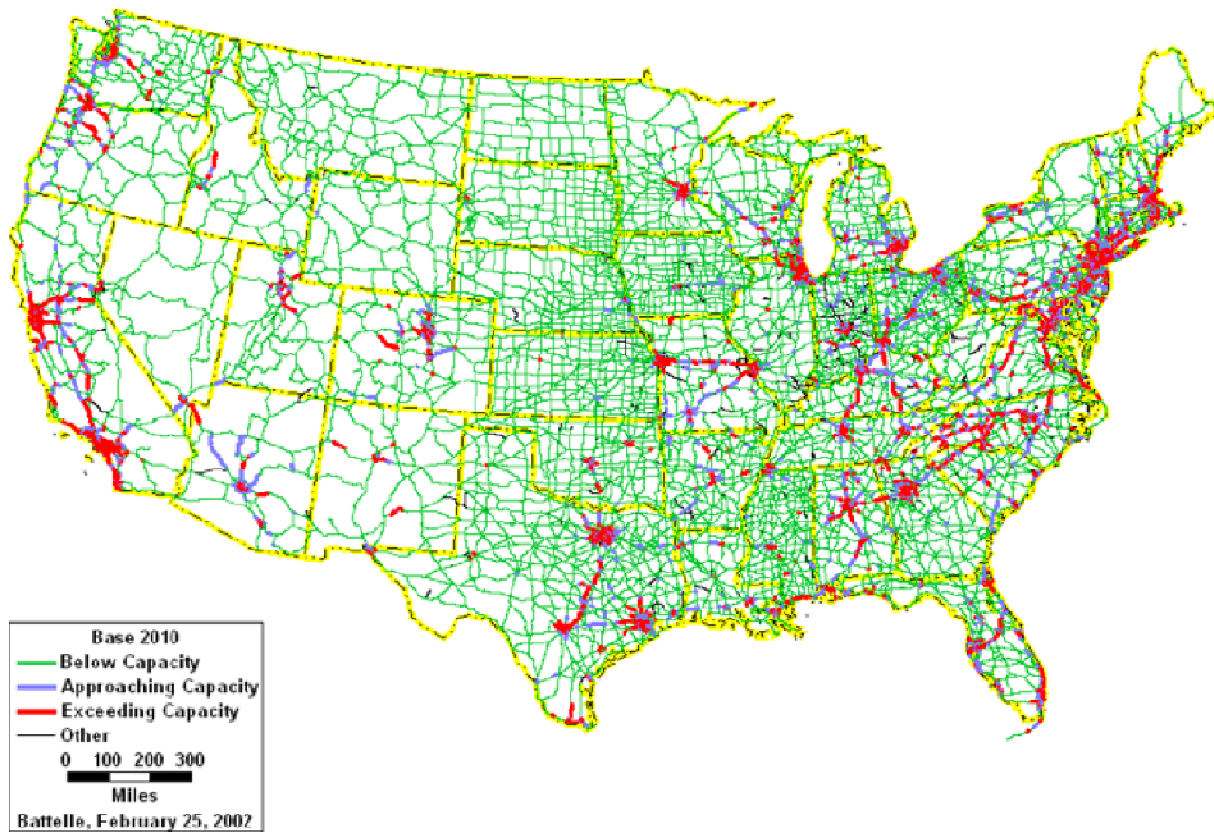


Figure 2. 2010 United States highway capacities

Figure 2 shows the projection for highway capacity in 2010. When compared to Figure 1, the two major corridors, I-5 in California and I-95 from Maine to Washington D.C., are projected to become more congested. Additionally there is an increase in traffic along corridors that connect metropolitan areas such as from Charlotte, NC to Atlanta, GA and from Kansas City, MO to St. Louis, MO. Although the map does not specifically show freight traffic, the short-haul journey is typically made using trucks. Many of the corridors showing growing capacity problems link major metropolitan areas, so it would not be difficult to conceive that freight movement between those metropolitan areas as a major contributor to the increase in traffic.

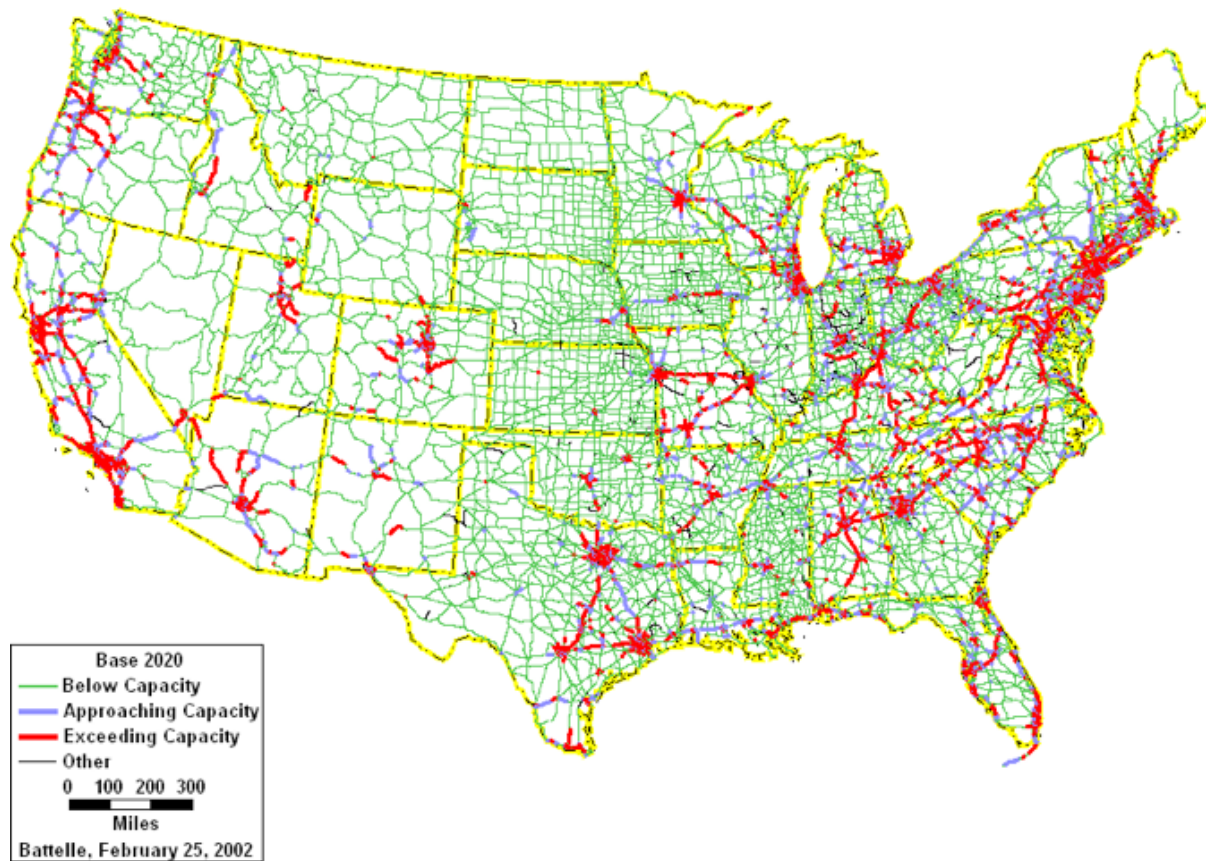


Figure 3. 2020 United States highway capacities

Figure 3 shows the projected highway capacities in 2020. The two major corridors, the I-5 and I-95, would be reaching capacity over nearly the entire stretch of their respective highway. Many of the major arterials east of the Mississippi River are projected to exceed capacity. In the year 2020, the interstate system would be celebrating its 64th anniversary and would be in a more deteriorated condition than it is currently. Given the current lack of resources to adequately maintain our nation's highways, and an inability to construct new infrastructure to meet demand, the US is left with a complex situation.

Although seeing the increase in congestion along some of our major freight corridors can be startling, the distribution of freight between the three predominant modes provides another glimpse at a system that is dependent on trucks traveling on an aging infrastructure system. Figure 4 shows the distribution of freight and this distribution can be linked up with Figure 1, Figure 2, and Figure 3 (Office of Freight Management and Operations, 2006). Although freight shipments are expected to grow, a disproportionate amount of that freight is projected to be

moved using trucks on the highway system. The increases in truck movement will result in the capacity issues noted previously.

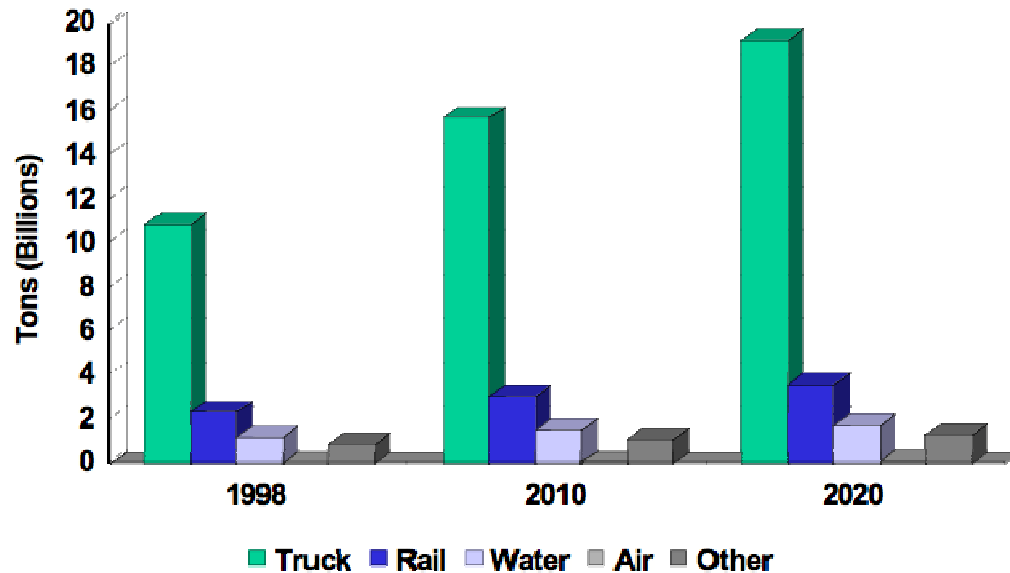


Figure 4. Distribution of freight

Growth is taking place on the other modes of freight transport, but none come close to the growth that is projected to take place in the trucking sector based on tons of freight moved. The air sector is expected to grow faster than any mode of transit based on energy use (U.S. Energy Information Administration, 2007). Figure 5 shows a similar look at the distribution of freight but with a more historic view by providing data back to 1980. The amount of freight being moved by truck has doubled during the past two decades. More sustainable modes, such as rail and ship, have not seen the same type of increase as truck. In fact, the use of ships has decreased over the past two decades and rail has seen only half of the increase that trucking has. In 2002, 64% of domestic freight shipments, by weight, were transported by truck, 10% by rail, and 3% by ship (Office of Freight Management and Operations, 2006).

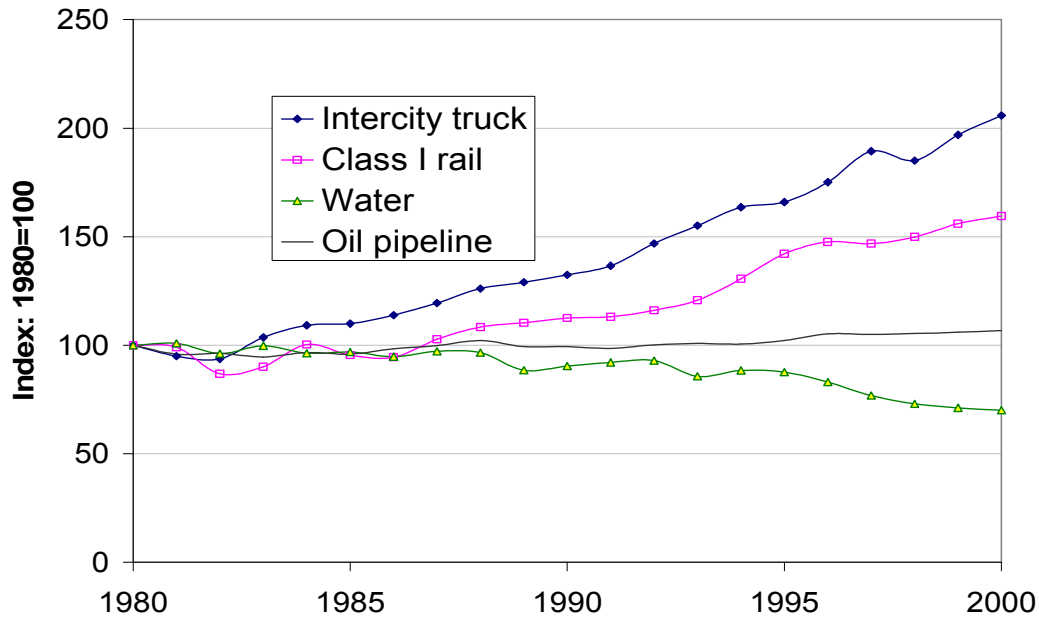


Figure 5. Current and historic distribution of freight by mode

Much of the reason for the lack of interest in the use of waterway transit is due to its perceived lack of efficiency and security (Shinghal and Fowkes, 2002). But with the obvious congestion problems and the environmental impact of truck/trailer freight movement, a solution needs to be determined to find a way to move freight in a more environmentally conscious way (Feitelson and Verhoef, 2001; Vanek and Morlok, 2000).

Freight transportation represents about 7% of the US Gross Domestic Product (GDP). As has been stated earlier the amount of freight is continually increasing as well as the value of freight (Bureau of Transportation Statistics, 2005; Greening, Ting, and Davis, 1999; Schipper, Scholl, and Price, 1997; Vanek and Morlok, 2000). According to the US Bureau of Economic Analysis exported and imported goods and services represented approximately 22% of US GDP in 2005, up from 12% in 1990 and 10% in 1970 as product manufacturing moved into the global marketplace. For example, the amount of US domestic ton-miles of goods transported via multiple modes rose 12.2% from 1993 to 2002, while the value of such goods leapt 68% (Bureau of Transportation Statistics, 2005).

Not only is the amount of goods being shipped increasing, but the value of those goods is also increasing. Typically, high valued goods are shipped quickly, based on need or receiver request, and are delivered using a door-to-door service. Because of the need for increased security and expeditious delivery, the rail and water modes of transit have a large disadvantage, given their perception of being slow and insecure. The best choice then, ends up being trucks to move freight securely and quickly. As more freight is being moved, the result is more trucks/trailers on the highways, resulting in increased costs and congestion.

The increase in truck traffic on our nation's highways will further congest many highways that already experience frequent backups and create congestion on segments of highway that may have been only minimally congested (Cambridge Systematics, 2005). The truck traffic will also increase at our nation's freight terminals. Currently many terminals experience delays in getting trucks into and out of terminals (T. F. Golob and Regan, 2000). The increase in freight traffic will further increase the delays and congestion as more freight is being moved through the transport system. The increase in truck traffic will also greatly impact a highway structure with bridges and overpasses, many of which are already labeled as needing replacement. The impacts on the highway infrastructure alone warrant immediate attention, but there are additional impacts accompanying domestic freight transport.

As previously noted, traffic congestion has emerged as a major challenge facing freight transportation along the Atlantic seaboard. Major cities such as Boston, Washington, DC, and Philadelphia lie on the I-95 corridor, and are among the top 12 most congested major metropolitan areas in the US (Cambridge Systematics, 2005). In 2005, it is estimated that traffic congestion caused over 112.3 million hours of delay for passenger car and truck drivers in the Philadelphia area, 62.4 million hours in Baltimore, and 8.3 million hours in Richmond (Schrunk, 2005). Additional travel time incurred by highway congestion also prompts excess fuel consumption, which subsequently leads to higher emissions and drives up costs for travelers (Ostria, 2004). Furthermore, trucks were identified as being a leading contributor to the increase in highway congestion with a rate more than double that of passenger cars (Ostria, 2004). Intermodal freight networks may create an opportunity to reduce this congestion along our major highways (American Association of State Highway and Transportation Officials, 2003).

3.2 Externalities of Freight Transportation

Energy use and emissions from freight transport are increasing at a more rapid rate than other types of transportation (Ang-Olson and Schroeder, 2002; Janic, 2007). In 2005 freight transport in the US accounted for about 7 trillion Btu (TBtu) of energy consumption, representing about 26% of total non-military transportation energy use. Freight transport energy consumption is anticipated to grow at an average rate of about 2% annually (compared to 1.4% for the transportation sector as a whole). By 2030 energy consumption from freight transport is expected to grow by nearly 60%, from the 2003 baseline, to 10,850 TBtu representing 28.6% of total transportation energy use (U.S. Energy Information Administration, 2007). As the US continues to increase its importing of international goods, the amount of energy consumed and emissions released will increase as a result. The increase in freight traffic in these corridors will increase congestion resulting in an increase in emissions in these areas. The increase in emissions will diminish the air quality near heavily traveled freight corridors, such as the I-95 corridor stretching from Maine to Florida and the I-5 corridor in California. Lower air quality in these areas can result in increases in health-related concerns, such as asthma.

The US Energy Information Administration (2007) has predicted significant increases in energy use in the freight sector due to these growth trends as shown in Figure 6. The energy consumption trends depict expected future growth of freight energy use by mode from 2005 to 2030. Much of the growth will occur in the truck and air sectors, which are traditionally the most energy- and carbon-intensive modes of freight transport (US Environmental Protection Agency, 2006). Figure 6 also shows the expected proportion of freight transport energy consumption relative to other transportation services between 2005 and 2030 (U.S. Energy Information Administration, 2007). Light-duty vehicles are represented in Figure 6 by “LDV” and light-duty trucks are represented by “LDT”. Truck freight is expected to grow about 20% between 2005 and 2030. A more sustainable mode, such as short-sea shipping is looking at an increase of only 2.5%. Consequently, the nation’s roads and highways are looking at a considerable increase in congestion and poorer air quality in many of our nation’s largest urban centers.

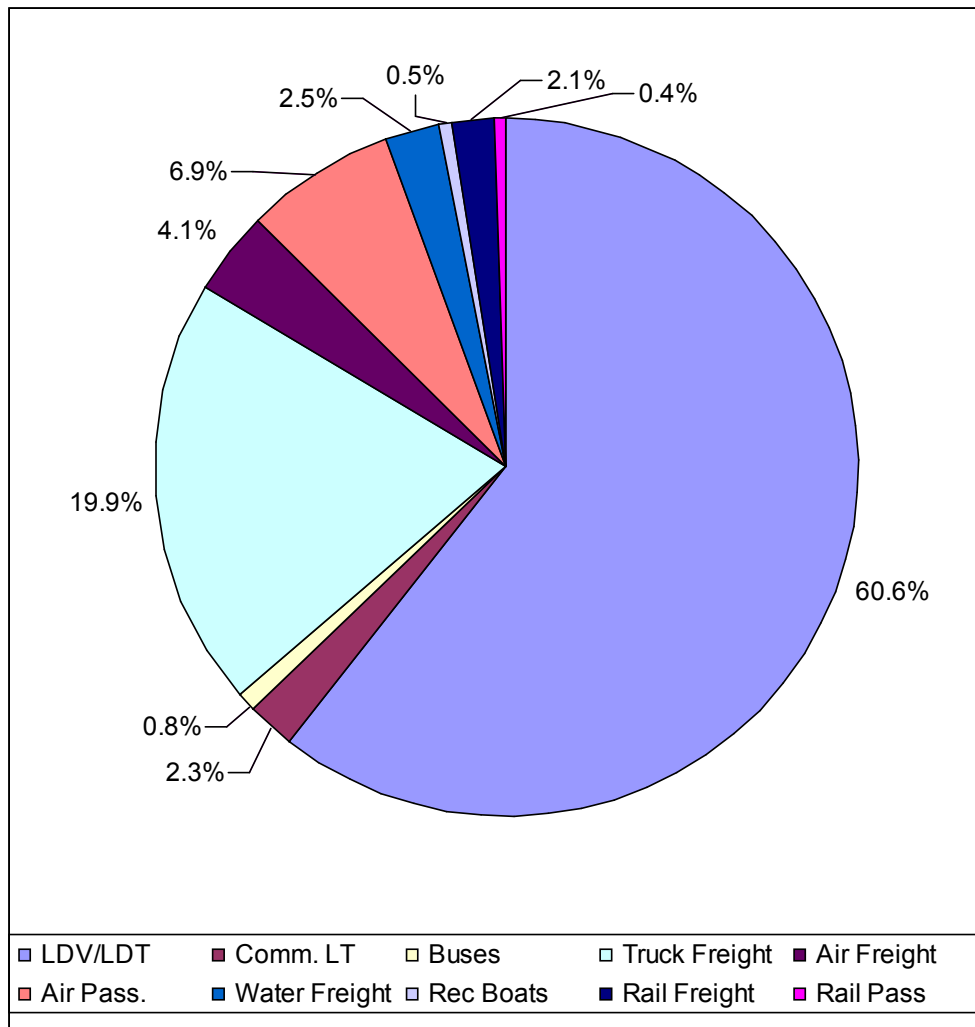


Figure 6. US freight energy demand 2005-2030

With increasing freight transport activity (and accompanying energy use), emissions are expected to increase at a similar pace. Prior research has noted these trends (Schipper et al., 1997). Currently, freight transport (including rail, truck, air, and domestic and international shipping to the US) is responsible for about 470 million metric tonnes of CO₂ (MMTCO₂) per year in the US, or about 8% of US fossil fuel CO₂ combustion emissions, and about 8% of total CO₂ emissions. This is consistent with other industrialized countries, such as Canada, where freight transport represents about 9% of total greenhouse gas emissions (Steenhof, Woudsma, and Sparling, 2006).

Trucking consumes more energy and contributes more GHG and pollutants than rail or water-based freight transportation. Even though freight trucks/trailers create negative externalities, a significant amount of freight is transported via truck because trucking is faster and more flexible while being about the same cost as rail and water. The US highway system allows trucks to move freight over large distances relatively quickly, and trucks can go virtually anywhere on land. The concept of door-to-door delivery fits very well with trucking. A shipment can leave a warehouse on a truck and be delivered directly to the receiver. To ship freight via rail and/or ship is slower and requires the added time and expense of moving freight from one mode to another, since most receivers of freight do not live on rail lines or near ports.

With concerns of global warming due to greenhouse gasses and health impacts of airborne pollutants, time and cost may no longer be the primary variables optimized in freight transportation. Modes of freight transportation that reduce energy consumption and harmful emissions may become equally (or more) important to society and the economy compared to modes that reduce time and cost, but difficulties still remain in creating economies of scale to help make ship and rail freight transport more competitive.

In addition to global pollutants such as CO₂, other emissions associated with transporting freight can be significant (Organisation for Economic Co-Operation and Development (OECD) and Hecht, 1997; Energy Information Administration, 1998; Skjølsvik, Andersen et al., 2000). US EPA data suggests that heavy duty truck, rail, and ship freight transport together account for about 50% of recent NO_x emissions and nearly 40% of the PM emissions from all mobile sources (Environmental Protection Agency, 2005).

Figure 7 shows the distribution of pollutants amongst the four major modes of freight transport. The largest portion of emissions from freight comes from heavy-duty trucks, which produce two-thirds of NO_x and PM₁₀ emissions. Emissions from marine vessels account for 18% of freight NO_x emissions and 24% of freight PM₁₀ emissions, followed by railroads at 15% NO_x and 12% PM₁₀. These pollutants are especially a concern for major freight thoroughfares along populated corridors, such as the Interstate 95 (I-95) corridor along the US east coast, and the Interstate 5 (I-5) on the west coast.

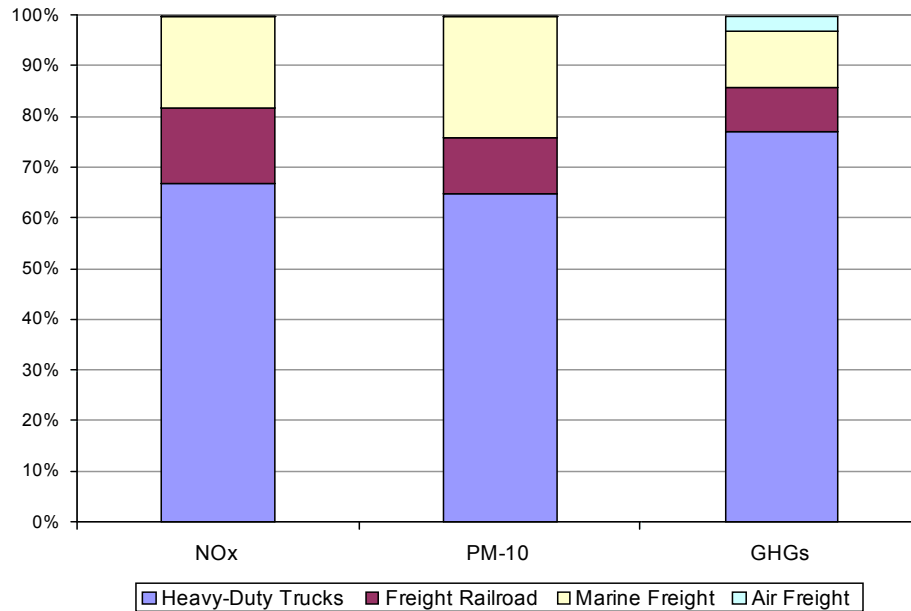


Figure 7. Emissions from US freight transport

Freight transportation is a significant contributor to greenhouse gasses (GHGs) and other emissions in the US. Currently, freight transport emits about 8% of fossil fuel CO₂ emissions and about 8% of total CO₂ emissions (CO₂ is a primary GHG) (Steenhof et al., 2006; U.S. Energy Information Administration, 2007). Freight transport is also a major source of local and regional air pollutants such as NO_x, SO_x, and particulate matter (Koopman, 1997). Freight transportation accounts for about 27% of all US NO_x emissions and about 50% of emissions from mobile sources, and it accounts for about 30% of 10 micron diameter particulate matter (PM₁₀) from mobile sources (Schipper et al., 1997; U.S. Energy Information Administration, 2007).

These results are consistent with earlier analyses that showed increasing energy use (and greenhouse gas emissions) in freight transportation in the US since the early 1970s (Schipper, Scholl et al., 1997; Greening, Ting et al., 1999; Vanek and Morlok, 2000). Similar trends are evident in the European Union (EU) (Koopman, 1997). Freight transport is not only a major concern because of its emissions but also because of the concentration of those emissions. The concentration of emissions from freight are often heaviest at ports, intermodal yards, and along major freight highway corridors which is clear given the quantity of freight traffic moving in and

around these areas. Consequently, these areas become difficult to live in or around given the pollution, noise, and traffic.

3.3 Prior Intermodal Models and Case Studies

Prior modeling work has been done worldwide to look at freight routing and the environmental impact of freight transport. Some models look at freight movement on a local/regional scale while others look at individual modes of transport. While some models use complex mathematical modeling to determine freight flow and environmental impacts, others use geographic software, such as ArcGIS, to construct their models. Although many models exist, few are able to bring together both logistics and environmental aspects to create a more holistic modeling approach.

Methodologies vary depending on the focus of the research. Some researchers focused their research on the creation of policy action plans to produce a modal shift in favor of intermodal transport (Tsamboulas et al., 2007). The authors used a policy tool called macro-scan which assesses the potential that specific policies have on the likelihood of intermodal shifts. Although the model provides sensational sensitivity analysis, it fails to acknowledge the energy and environmental aspects of freight transport. Other authors have looked at intermodal transport, but only incorporated rail and truck transport (Arnold, Peeters, and Thomas, 2004). Overall, a number of researchers have concluded that intermodal transport is a worthwhile alternative to unimodal transport (Ang-Olson and Schroeder, 2002; Arnold et al., 2004; Boile, 2000; Lombardo, Mulligan, and Guan, 2004; Vanek and Morlok, 2000).

Researchers have used complex algorithms to calculate the probability of intermodal transfers and the effect that they will have on a variety of variables (Chang, 2007; Sivakumar and Bhat, 2000). The advantage of models such as these is that the authors have full control over the algorithms that are used, how they are used, and the data that are used in them. A disadvantage to the models is their incredible complexity and lack of usability by policymakers. Although the authors may be able to use the model and conduct adequate sensitivity analysis, it becomes nearly impossible to allow others to interact with the model without detailed instruction as to how to use it. Recently, a transition has been made to look more closely at using modeling techniques that utilize the GIS platform (Bachman, Sarasua, Hallmark, and Guensler, 2000;

Boile, 2000; Boxill, 2005; Filipov and Davidkov, 2005; F. Southworth, and Bruce E. Peterson, 2000; F. Southworth, Xiong, and Middendorf, 1997; Standifer and Walton, 2000). By utilizing the capabilities of GIS, researchers have been able to not only construct transport networks, but also utilize the visual advantages that GIS provides. The ability to visualize the transportation networks provides another dimension that mathematical models lack.

Although some of the prior intermodal models have been developed to study freight flow across intermodal networks, only a few utilize GIS to construct an intermodal network to model freight flow (Arnold et al., 2004; Boile, 2000; Janic, 2007; Luo and Grigalunas, 2002; F. Southworth, and Bruce E. Peterson, 2000; F. Southworth et al., 1997; Standifer and Walton, 2000). Southworth and Xiong (1997) wrote one of the first papers discussing the construction of an intermodal network using GIS. The authors created an intermodal network by combining highway, rail, water, and air freight transportation. As noted by the authors, a key to realistic freight routing is the identification of intermodal locations associated with terminal functions and the integration of accurate cost functions. The methodology highlighted the use of both real and notional connectors for the intermodal network (Southworth 1997). Real connectors were either local access roads or rail spurs that connect a modal segment to an intermodal terminal. The notional connector is an artificial connector linking one mode to another, but this link is only a representation and not a physical link. A major difficulty noted by the authors was the inability to connect the separate modes into a cohesive routable network.

Southworth (2000), building off of his original work, proposed an approach to connect the separate modal networks into a cohesive intermodal network. The author utilized the Commodity Flow Survey to obtain the origin and destination points for the network and conducted the computational component outside of GIS. The Commodity Flow Survey provides data about the type of goods being shipped; the mode(s) used during the journey, the distance travelled on each mode, and the origin and destination zip codes for the goods being moved. These types of data provide a good macro-level view of freight movement in the US, but fail to incorporate the costs associated with moving freight, including the transfer costs associated with switching goods between different modes. Although the authors create a routable intermodal network within GIS, the model still lacked any environmental data or cost data to use when conducting an optimization. This is due in part to the model not being an optimization model but

more of a model to validate and understand the data that are received from the Commodity Flow Survey. Boile (2000) conducted similar research in producing an intermodal network within GIS that can be used as more of a logistics tool. The computation takes place outside of GIS within a General Algebraic Modeling System (GAMS). GAMS is a high-level modeling system for mathematical programming and optimization. An advantage of using an external software for computation, such as GAMS, is that capacity models and cost models can be loaded into GAMS to be used in the model, but detail is not provided as to how, or if this type of activity is even possible.

Standifer and Walton (2000) created an intermodal network focused on the state of Texas. The authors were able to create a cohesive intermodal network in GIS integrating rail, ocean, inland waterway, and truck modes with transfer facilities. The authors were one of the first to utilize the Network Analyst extension within ArcView GIS to create their intermodal network. The authors also utilized the concept of real and notional connectors as noted in Southworth (1997). The model was utilized by the authors to find least time and least cost routes for freight within the state of Texas. The authors also used the model to look at policy issues such as terminal construction and improvement and cost variations. This model went further than prior models by using the model as a policy tool, but given its focus on only the state of Texas, it was difficult to obtain the true impact of a policy decision.

Although there have been a variety of different methodologies proposed for intermodal network creation, there are only a handful of case studies conducted by authors who have utilized intermodal networks. Three reports in particular conduct corridor case studies using their own modeling methods (Casgar, DeBoer, and Parkinson, 2003; Global Insight and Reeve and Associates, 2006; National Ports and Waterways Institute, 2004). The models all contain the standard modeling costs, such as operating costs and drayage costs, but lack an energy and environmental aspect. If energy is included in the model, it is included as part of the operating cost.

A study conducted by Global Insight (2006) examined short-sea shipping in four key domestic corridors. The corridors included in the study were the Gulf of Mexico/Atlantic Coast Corridor, the Atlantic Coast Corridor, the Pacific Coast Corridor, and the Great Lakes Corridor. The

intention of the Global Insight study was to better inform policymakers in developing a framework that will help to support short-sea shipping initiatives. Given the lack of understanding of the market factors related to short-sea shipping, the report examined the costs related to short-sea and intermodal freight movement.

The Global Insight report used a business model based on industry costs for ocean and land transport, container, trailer, and chassis equipment, marine terminal operations, other logistics expenses, asset depreciation, and sales and administrative overhead developed using measures of fixed and variable costs (Global Insight and Reeve and Associates, 2006). The inclusion of these data makes the Global Insight report valuable for those who are trying to understand the costs associated with both short-sea and intermodal freight movement and their respective impact on route selection. Much like other short-sea models, the traffic flows with a distance of less than 500 miles were eliminated from the study because these traffic flows would be infeasible for short-sea service, given their short distance. By eliminating the traffic distance of less than 500 miles, the case studies make it difficult to conduct tradeoffs between freight journeys of varying distances. Also, given the current focus on just-in-time and door-to-door delivery, including highway traffic of less than 500 miles would prove to be highly useful to uncover ways to make short-sea freight movement more efficient and competitive with both rail and trucking.

For the purpose of this research, the case study conducted on the Atlantic Coast Corridor was utilized. The corridor lies between the port catchment areas of Port Canaveral, FL and New Haven, CT. The rail intermodal direct operating cost elements included in the Global Insight study included locomotives and fuel, track and right-of-way, yard and terminal operations, lift-on and lift-off movements, railcar, crew, trailer/container, and drayage expense (Global Insight and Reeve and Associates, 2006). Shown in Table 1 are the results of the Atlantic Coast Corridor short-sea shipping case study (Global Insight and Reeve and Associates, 2006). The costs noted in the table are per container, which would be the equivalent of an FEU or two TEUs. The case study concluded that short-sea shipping provided a discount of 42% compared to the cost of highway transport.

Table 1. Global Insight short sea shipping case study results

Short-Sea Shipping	
OPERATING STATISTICS	
Ocean and Dray Miles	1289.05
Transit Hours	70
Projected Door-to-Door Transit	70
ESTIMATED OPERATING COSTS (Per Load)	
Vessel Costs	\$279
Fuel Costs	\$87
Port Charges	\$18
All Other	\$42
Marine Terminal Costs	\$129
Trailer/Container Costs	\$51
Drayage Expense	\$438
Depreciation (included in vessel costs)	
Total	\$1,045
Estimated Operating Cost per HWY Mile	\$0.88
Estimated Markup	\$0.09
SHIPPER COSTS	
Shipper HMT Expense	\$24
Incremental Inventory Carrying Cost	\$14
Total	\$38
Estimated Shipper Cost per HWY Mile	\$1
Discount vs. Highway Transport	42%

The Short Sea Cooperative Program (SCOOP) case study report analyzed the public benefits of the Short Sea Intermodal System (SSIS). The report analyzed two routes. The first route was a short-haul route between New York City (NYC) and Boston, MA. The second route was a long-haul route from NYC to Miami, FL with stops in Norfolk, VA and Charleston, SC. The researchers wanted to test the sensitivity of the required freight rates (RFR) and the trip time to various assumptions such as capital cost, cost of labor, and the cost of fuel. Shown in Table 2 are the results of the case studies (National Ports and Waterways Institute, 2004). The results of the SCOOP case study showed that the short-sea shipping option was the cost effective option for both the long and short-haul freight journeys. In both cases the unit cost for short-sea shipping was roughly \$0.30 less than the unit cost for trucking.

Table 2. Comparison of SCOOP case studies

Comparison of Case Studies			
Description	Unit	NYC -- Miami	NYC -- Boston
Cost Comparison			
Total Point-Point Cost	\$/Trailer-Trip	1460	449
Distance	Statute Mile	1331	190
Unit Cost, Ferry	\$/SM	1.1	2.37
Average Truck Rates	\$/Trailer-Trip	1795	500
Unit Cost, Truck	\$/SM	1.35	2.64
Cost Diff. (Ferry-Truck)	\$/Trailer-Trip	-335	-51
Time Comparison			
Terminal-Terminal, Ferry	Days	2.34	0.47
Point-Point, Truck	Days	3	1

The Foundation for Intermodal Research and Education conducted a study that analyzed short-haul intermodal rail in three corridors (Casgar et al., 2003). The corridors include Savannah, GA to Atlanta GA, the Port of New York/New Jersey (PONYNJ) to Buffalo, NY, and the PONYNJ to Pittsburgh, PA. The objective of the study was to inform public officials of the costs and benefits associated with short-haul intermodal freight service.

The corridor case study which is closest to what was being modeled using the GIFT model was the corridor from Savannah, GA to Atlanta, GA. Shown in Table 3 were the results from the Savannah to Atlanta case study (Casgar et al., 2003). The results of the FIRE case study are different than the previous two case studies in that they are not comparisons to other modes of transit. The FIRE case study provides detail on the micro-level costs associated with truck to rail intermodal freight transport. The costs reported in the case study were useful in constructing the GIFT model.

Table 3. Results from FIRE case study

Cost Analysis-CSX Corridor Savannah-Atlanta			
Length of haul			
Power: 2 hp/ton, 2-4,000 hp locomotives = 8,000 hp/or 1-4,000 hp locomotive			
Fuel consumption: 3 gal. per mile per locomotive			
Train weight = 3800 tons, trailing tons at 3400 (200 FEUs) or 1700 tons (100 FEUs)			
Schedule: 16 hours			
Units: 200 FEUs or 100 FEUs			
	Two Locomotives Pulling 200 FEUs (\$)	Two Locomotives Pulling 100 FEUs (\$)	One Locomotive Pulling 100 FEUs (\$)
Line Haul Costs			
Train-miles (319 train-miles x \$3.53)	1126	1126	1126
Crew \$8.30 x 319	2648	2648	2648
MOW 3800 tons (incl. locomotive) x 319 mi./1000 tons x \$0.88	1067	533 (1900 tons)	477 (1700 tons)
Switching (\$4.35 x 60 minutes)	261	130 (30 minutes)	130
Locomotive maintenance = units x 319 mi. x \$1.17/mi	746	746	373
Fuel \$0.87 x units x 3 gal/mi x 319 mi.	1665	1665	833
Locomotive capital costs \$35.00 x units x 16 hr.	1120	1120	560
Daily car lease costs 20 double stack cars x \$45.36 x 3 days	2722	1361 (10 cars)	1361 (10 cars)
Per mile car costs = \$0.068/mi. x cars x 319 mi.	434	217 (10 cars)	217 (10 cars)
Subtotal	11789	9546	7725
Terminal Costs			
Two lifts (origin and destination) @ \$125 per lift	25000	12500	12500
One move at both origin and destination @ \$150 per move	30000	15000	15000
Total Line Haul, Terminal and Drayage Costs	66789	37046	35225
Cost Per Box (div. by 200 or 100)	334 (200 FEUs)	370 (100 FEUs)	352 (100 FEUs)
Cost Per Box-mile (319 mi.)	1.05	1.16	1.1
Cost x 1.4 (long-run variable cost multiplier	1.47	1.62	1.54

This thesis uses the three case studies and their results as a benchmark to compare the GIFT model to. Since it was not feasible to collect all of the necessary data to create the intermodal model, and since other models failed to incorporate both energy and environmental impacts in their models, the best available approach was to utilize existing data and case studies in order to create the GIFT model. The following section describes the methodology that was used to create the model and how the different costs were calculated and eventually incorporated into the model.

4. Methodology

4.1 Overview of the Intermodal Network Model

The GIS software utilized to create the intermodal network was ArcView 9.1 from ESRI. The software comes with an assortment of extensions which can be utilized for different purposes. The extension that was utilized to create the intermodal network was the network analyst extension. The following section outlines the methodology that was used to calculate the different costs for the segments and transfers in the GIFT model and how the intermodal network was created using ArcGIS. The GIFT model is focused on the following variables:

- VOC – Volatile Organic Compounds
- CO – Carbon Monoxide
- CO₂ – Carbon Dioxide
- SO_x – Sulfur Dioxide
- NO_x – Nitrogen Dioxide
- PM₁₀ – Particulate Matter
- Btu – British Thermal Unit
- Hr – Time
- Monetary Cost – US Dollar

Carbon monoxide, sulfur dioxide, nitrogen dioxide, and particulate matter were chosen as pollutants to be measured in the model because of their status as criteria pollutants according to EPA. PM₁₀ was specifically selected because of its ability to settle in the bronchi and lungs causing health problems such as asthma. Carbon dioxide was a GHG measured in the model because it is the leading GHG produced by human activities. Volatile organic compounds were included in the study because they include methane and methane is a potent greenhouse gas with a large impact on global warming.

Velocities were measured for all three modes using miles per hour. Time is measured using hours and the monetary cost is calculated using the US Dollar. In order for the model to be as

accurate as possible it was imperative to find the most accurate data available. The required data came in three different parts:

- Emissions Data
- Energy Data
- Operation Costs and Time

4.2 Segment and Transfer Emissions Calculation Methodology

The calculations are broken down into two distinct types: segments and intermodal transfers. The modes of transport being used on each segment are important to note. The highway segment was modeled using data from standard heavy-duty vehicles (HDV). Rail was modeled using data from standard intermodal rail. The ship segments were modeled with the ship most often noted in short-sea shipping studies, the roll-on/roll-off (RORO) shipping vessel (Brooks, Hodgson, and Frost, 2006; Casgar et al., 2003; Global Insight and Reeve and Associates, 2006). The advantage to using this type of vessel was its versatility in carrying freight which can be easily transferred between modes.

The segment emissions were broken down by each mode of transportation (truck, rail, and waterway). The emissions for rail and truck were from the GREET model.² Data were taken from the GREET model and input into the TEAMS model.³ The following tables show each of the modes and their corresponding segment emissions. Table 4 and

Table 5 show the emissions in grams per TEU-mile for both the rail and truck segments that were input into the GIFT model.

² GREET can be found at (<http://www.transportation.anl.gov/software/GREET/>)

³ The TEAMS model can be found at (<http://www.rit.edu/~teams/>)

Table 4. Rail Emissions

RAIL	g/MBtu	Btu/ton-mi	Tons/TEU	g/TEU-mi
VOC	74	370	7	0.2
CO	213	370	7	0.6
NO _x	1517	370	7	4
PM ₁₀	36	370	7	0.1
SO _x	17	370	7	0.04
CO ₂	77,623	370	7	201

Table 5. Truck Emissions

TRUCK	g/truck-mi	TEU/truck	g/TEU-mi
VOC	1	2	0.3
CO	3	2	2
NO _x	14	2	7
PM ₁₀	0.2	2	0.1
SO _x	0.4	2	0.2
CO ₂	2,002	2	1001

The shipping segments were calculated using exclusively the TEAMS model. The TEAMS model was input with a one mile trip averaging 20 mph, using residual oil for both the main and auxiliary engines. Data reflecting the RORO ocean-going vessel is shown in Table 6 (Corbett, 2006; Corbett, Wang, and Firestone, 2006).

Table 6. Ship Segment Emissions

SHIP	g/ship-mi	TEU/ship	g/TEU-mi
VOC	232	200	1.2
CO	1045	200	5.2
NO _x	5985	200	30
PM ₁₀	195	200	1
SO _x	665	200	3
CO ₂	218787	200	1094

The next section outlines the calculations that were used to determine the segment emissions for each of the modes used in the GIFT model.

4.3 Segment Energy Consumption Calculations

Truck Segment

To determine truck segment energy consumption, Equation 1 was used.

$$E = \frac{\rho}{n \cdot c}$$

Equation 1. Truck energy usage calculation

where E represents energy intensity of moving freight in Btu/TEU-mi; η is the efficiency of trucks in miles per gallon; ρ is the energy density of fuel in Btu/gallon; and C is the capacity of trucking in TEU/truck. For the purpose of the calculation $\eta = 6$, $\rho = 128450$, and $C = 2$. Using this equation and data the overall energy consumption of trucks was calculated to be 10,704 Btu/TEU-mi.

Rail Segment

To determine the energy usage on the rail segments, Equation 2 was used for the calculation.

$$E = \rho \cdot C$$

Equation 2. Rail energy usage calculation

where E represents energy intensity of moving freight in Btu/TEU-mi; ρ is the energy intensity of fuel in Btu/Ton-mi; and C is the capacity of rail in tons/TEU. For the purpose of the model $\rho = 370$, and $C = 7$. This equation and data provided resulted in rail energy consumption of 2590 Btu/TEU-mi for rail freight traveling in the GIFT model.

Waterway Segment

To determine the energy usage on the waterway segments, Equation 3 was used for calculation.

$$E = \frac{\rho}{C}$$

Equation 3. Waterway energy usage calculation

where E represents energy intensity of moving freight on the waterway segment in Btu/TEU-mi; ρ is the energy consumption in Btu/Ship-mi; and C is the capacity of the shipping vessel in TEU/Ship. For the purpose of the calculation $\rho = 2600000$, and $C = 200$. The numbers used were from the TEAMS model. Using this equation and data the energy efficiency on the waterway segments is calculated to be 13,040 Btu/TEU-mi. Table 7 shows the energy consumption per TEU-mile for each of the three modes of freight transport in the GIFT model.

Table 7. Segment energy usage by mode

Transport Mode	Btu/TEU-mi
Truck	10704
Rail	2590
Ship	13040

4.4 Segment Time and Operating Cost Calculation

A critical aspect of modeling freight movement is the time and cost aspect of the movement. The time aspect of the segments was calculated using Equation 4.

$$t = \frac{d_{ijk}}{v_{ijk}}$$

Equation 4. Segment time calculation

where t represents the time in hours from i to j using mode k ; d represents the distance from i to j using mode k ; and v represents the velocity from i to j using mode k .

Highway Velocity

The National Transportation Atlas Database (NTAD) is a set of transport-related geospatial data for the US. These data consists of various transport network, facilities, and other spatial data. These data can be easily uploaded for use in ArcView. NTAD supplies a feature class attribute for each segment in the highway network. NTAD and these feature classes align with a specific type of highway. The velocities are estimates based on the classifications noted in NTAD and the speeds used are from ESRI's StreetMap. StreetMap is an additional extension found within ArcView. StreetMap allows users to conduct nationwide street mapping across the US.

For the purpose of the model, the StreetMap extension was only used as a benchmarking tool to determine approximate speed limits for highway segments. Many difficulties were encountered when attempting to align speed limit values in the GIFT network. The approach that was used provides an approximate estimate of the speed limits on the different segments in the model. The best attempt was made to match up the feature classes from the NTAD and StreetMap databases. The feature classes noted in

Table 8 are found in the attribute table of the National Highway Planning Network (NHPN) polyline shapefile located in the NTAD dataset. The highway types were aligned to the feature types in the ArcView StreetMap attribute table in order to obtain approximate speed limits.

Table 8. Highway segment velocities

Highway Velocities		
Feature Class	Type	Velocity (mph)
0	Unidentified	55
1	Rural Principal Arterial - Interstate	65
2	Rural Principal Arterial - Other	55
6	Rural Minor Arterial	30
7	Rural Major Collector	50
8	Rural Minor Collector	40
9	Rural Local	30
11	Urban Principal Arterial - Interstate	55
12	Urban Principal Arterial - Other Freeways	50
14	Urban Principal - Other	40
16	Urban Minor Arterial	30
17	Urban Collector	40
19	Urban Local	30

Rail Velocity

The velocities on the rail segments found in

Table 9 were calculated using the standard freight speed limits as noted by the Federal Railroad Administration and the US Department of Transportation.⁴

Table 9. Rail segment velocity

Rail Velocities		
Railroad Class	Type	Velocity (mph)
1	Class I Railway	10
2	Class II Railway	25
3	Class III Railway	40

Waterway Velocity

Waterway network segment velocities were determined based on the function class of the waterway segment. The function class attribute located in the waterway network attribute table; stated the function of the waterway segment. The velocities for each of the segments in Table 10 are estimated, based on waterway type, using a variety of prior intermodal studies (Brooks et al., 2006; Corbett, 2006; Global Insight and Reeve and Associates, 2006; National Ports and Waterways Institute, 2004; Standifer and Walton, 2000). An assumption was made to give a zero velocity to segments noted as being non-navigable or for special vessels only since freight would not be using those segments during its journey.

⁴ Speed limits for rail traffic can be found in track safety standards (49 CFR 213.9)

Table 10. Water segment velocity

Waterway Velocities		
Function Class	Type	Velocity (mph)
N	No Traffic, Non-Navigable	0
S	Shallow Draft (No Deep Draft OGV)	10
D	Deep Draft	20
B	Both (S+D)	15
U	Special Vessels Only	0

Operating Cost

There are three separate operating costs based on the segment being used within the GIFT model. The costs for traveling on the highway segment, rail segment, and waterway segment can be found in Table 11. Data were collected from to aid in the determination of operating costs for individual segments within the GIFT model (Global Insight and Reeve and Associates, 2006). Equation 5 shows the summation of each of the segments to calculate total operating cost.

Table 11. Segment operating cost

Transport	Cost
Truck	\$0.87
Rail	\$0.55
Ship	\$0.50

$$C_{ij} = \sum C_{ijk} \cdot X_k$$

Equation 5. Operating cost calculation

where C_{ij} is the operating cost from i to j ; k is the mode being used during transit; and X is a binary number used to denote whether a particular mode was used during transit.

4.5 Intermodal Transfer Data Collection and Calculations

In order to determine the emissions, energy consumption, operating cost, and time penalties to attribute to the intermodal transfers in the GIFT model, a value per TEU transfer was calculated. The cost was calculated by using the total TEUs moved at a port in order to determine all costs based on a per TEU basis. Table 12 shows the annual TEU movement at the Port of Los Angeles/Long Beach (Starcrest Consulting Group, 2005). These data were used because of their completeness, which helped to maintain consistency with other data used in the model. The emissions data were taken from the same report. The calculations for this research used the final TEU total of 5,183,520 when determining the emissions, energy, time, and cost attributes for the intermodal transfers on a per TEU basis.

Table 12. 2001 TEU totals for the Port of Los Angeles/Long Beach

Month	Total TEU
January	396,993
February	330,431
March	401,636
April	417,430
May	400,011
June	435,245
July	451,856
August	477,059
September	484,654
October	505,020
November	455,505
December	427,680
Total CY 2001	5,183,520

Given the data that were reported in the Port of Los Angeles Emissions Inventory, a fair amount of recalculation of the data were necessary in order to obtain the necessary grams per TEU units that were required to determine the intermodal transfer costs in the GIFT model. Also, the six pollutants being measured in the GIFT model were not reported for all sources in the report. The following section describes how the necessary pollutants were derived from the information provided in the report and how the data were converted into grams per TEU for the GIFT model.

Determining Carbon Dioxide (CO₂) using Sulfur Emissions

Since the emissions inventory did not explicitly state the CO₂ for all point sources, it was necessary to use the SO_x that were reported for a given point source in order to calculate the CO₂. The following bullets outline the specific steps that were taken to determine CO₂.

- $\text{g SO}_x / \text{TEU} \times 32/64 = \text{g S/TEU}$
- Divide the g S/TEU by the Sulfur ratio (0.0229) to obtain the fuel use (g/TEU)
- Multiply fuel use by the carbon ratio (0.865) resulting in g C/TEU
- To obtain g CO₂/TEU multiply g C/TEU by the fuel use ratio of 44/12

Converting Total Organic Gasses (TOG) to Volatile Organic Compounds (VOC)

Some of the emissions data that were acquired were reported as TOG, but in order to maintain consistency with the rest of the data in the model it was necessary to convert TOG to VOC. In order to calculate the necessary VOC from the provided TOG Equation 6 was used.

$$b = w \cdot Q$$

Equation 6. Total organic gases to volatile organic compound conversion factor

where b is the amount of VOC; w is the amount of TOG as reported in the Port of Los Angeles Emissions Inventory; and Q is the VOC conversion factor as reported by the EPA. In this case, Q is 0.984.

Converting Hydrocarbons to Volatile Organic Compounds (VOC)

In order to maintain data consistency, the data that were reported as HC needed to be converted to VOC. In order to calculate VOC from the provided HC Equation 7 was used.

$$b = p \cdot h$$

Equation 7. Hydrocarbon to volatile organic compound conversion factor

where b is the amount of VOC; p is the amount of HC as reported in the Port of Los Angeles Emissions Inventory; and h is the HC conversion factor as reported by the EPA (Environmental Protection Agency, 2004). In this case h is 1.053. The emissions inventory for the Port of LA/Long Beach shows the emissions from a variety of sources. To convert from horsepower to Btu per hour the horsepower for the ocean-going vessel was multiplied by 2,545. To convert from the tons per year reported in the emissions inventory, it was necessary to divide the tons per year by the product of the total annual port TEUs (Starcrest Consulting Group, 2005).

Intermodal Transfer Emissions Calculation

In order to determine the emissions to be attributed to intermodal freight transfers it was necessary to determine the types of activities that took place when freight was being transferred from one mode to another. There are three types of transfers modeled in the GIFT model:

- Ship to/from Rail
- Ship to/from Truck
- Truck to/from Rail

The types of equipment used and the length of time to complete each transfer are different, depending on the type of transfer that is being made. Since it is impossible to understand or fully predict how each TEU is moved between modes, assumptions were made. A basic assumption was that each of the three modes of transport (truck, rail, and ship) all maneuvered, or are at an idle state, at some point during the freight journey on the terminal site. Also, different types of equipment were used to transfer the freight between modes. Table 13 shows the emissions from cargo handling equipment (Starcrest Consulting Group, 2005).

Table 13. Cargo handling equipment emissions

Source Category (g/TEU)	NO_x	VOC	CO	PM₁₀	SO_x	CO₂
Cargo Handling Equipment	330	35	127	20	8	535

The model assumes on-port rail transfers, as opposed to the off-port rail transfers that require trucks to be used to move trailers to the intermodal rail yard that are located off of the port site. The chart below shows all of the emissions associated with rail movement at the port air basin. For the purpose of this model, the emissions data for in-port switching, found in Table 14, were used (Starcrest Consulting Group, 2005). The out-of-port switching is not modeled in GIFT.

Table 14. Port locomotive operating emissions

Locomotive Operation (g/TEU)	NO_x	CO	PM₁₀	SO_x	VOC	CO₂
In-Port Switching	30	3	1	1	1	12

The model takes into account, when calculating the intermodal transfer emissions, the heavy duty vehicle maneuvering and idling that takes place on port, as noted in Table 16.

Table 15. Port heavy-duty vehicle emissions

On-Terminal HDV Emissions (g/TEU)	NO_x	CO	PM₁₀	SO_x	VOC	CO₂
Transit	21	10	1	1	2	11
Idling	30	10	1	1	0	9
Totals	51	20	2	1	2	20

Finally, the auxiliary engine usage during the hotelling process was used in the GIFT model. Hotelling is interpreted as the idling of ocean going vessels. Table 16 shows the emissions attributed to the auxiliary engine usage (Starcrest Consulting Group, 2005).

Table 16. Roll-on/Roll-off auxiliary engine hotelling emissions

	NO_x	CO	PM₁₀	SO_x	VOC	CO₂
Type of vessel (g/TEU)	Auxiliary Hotelling	Auxiliary Hotelling	Auxiliary Hotelling	Auxiliary Hotelling	Auxiliary Hotelling	Auxiliary Hotelling
Roll-on/Roll-off	4	1	1	3	1	195

Conceptually, the intermodal actions calculated in the GIFT model are described below and helps to demonstrate how the GIFT model calculated costs for each of the intermodal transfers. It is important to note that the calculations are the same for transfers in the opposite direction (rail to ship, truck to ship, and rail to truck).

- **Ship to/from Rail** = Cargo Handling Equipment Emissions + In-Port Rail Switching Operations Emissions + Roll-on / Roll-off Auxiliary Hotelling Emissions
- **Ship to/from Truck** = Cargo Handling Equipment Emissions + On-Terminal HDV Emissions + Roll-on / Roll-off Auxiliary Hotelling Emissions
- **Truck to/from Rail** = Cargo Handling Equipment Emissions + On-Terminal HDV Emissions + In-Port Rail Switching Operations Emissions

The calculations of the intermodal transfer emissions were done using Equation 8:

$$\sum h(T) + q(T) + r(T) + s(T)$$

Equation 8. Calculation of intermodal transfer emissions

where h is the cargo handling equipment emissions; q is the rail switching emissions; r is the on-terminal HDV emissions; s is the auxiliary engine emissions from the roll-on / roll-off ocean-going vessel; T is a binary number (0 or 1) used to denote whether or not certain sources are being calculated within the equation. Table 17 shows the emissions that were calculated for the intermodal transfers in the GIFT model (Starcrest Consulting Group, 2005).

Table 17. Roll-on / Roll-off intermodal transfer emissions

Ro/Ro Intermodal Transfers, g/TEU	NO_x	VOC	CO	PM₁₀	SO_x	CO₂
Ship To Rail	360	37	130	20	11	741
Ship To Truck	380	37	147	22	11	749
Truck to Rail	407	39	150	22	8	567

4.6 Intermodal Transfer Energy Calculation

The intermodal transfer energy calculation, described in detail below, was very similar to the intermodal transfer emissions calculations. The activities that take place are identical to those modeled in the emissions calculations and therefore the calculations are conceptually the same. The results of the calculations can be found in Table 18.

- **Ship to/from Rail** = Cargo Handling Equipment Emissions + In-Port Rail Switching Operations Emissions + Roll-on / Roll-off Auxiliary Hotelling Emissions
- **Ship to/from Truck** = Cargo Handling Equipment Emissions + On-Terminal HDV Emissions + Roll-on / Roll-off Auxiliary Hotelling Emissions

- **Truck to/from Rail** = Cargo Handling Equipment Emissions + On-Terminal HDV Emissions + In-Port Rail Switching Operations Emissions

Table 18. Energy usage for rail switching at port

Fuel Use Estimate for In-Port Switching			
Factor	Value	MBtu	Btu/TEU
Estimated fuel use (gal/yr)	614615	79900	15414

The value of the column Btu was determined by multiplying the estimated fuel use in gal/yr by 130,000 which is the amount of Btu in a gallon of fuel. The Btu/TEU value was determined by dividing the Btu value by the amount of total TEU's moving per year at the Port of Los Angeles/Long Beach as noted in Table 12.

The cargo handling equipment energy usage was also calculated for use in the GIFT model. The results of the calculations can be found in Table 19 which shows the Btu/TEU for the cargo handling equipment on port (Starcrest Consulting Group, 2005).

Table 19. Port cargo handling equipment energy usage

CHE Container Berth (On Port)	Avg. HP	Hours of Operation	Btu/hr	Total Annual MBtu	Btu/TEU
Yard Tractors	191	2400	486095	1167	225
Top Handlers	278	1732	707510	1225	236
Side Handlers	183	2400	465735	1118	216
RTG Cranes	388	1000	987460	987	191
Forklifts	150	1173	381750	448	86
Total					954

The heavy-duty vehicle (HDV) energy usage also needed to be addressed in the GIFT model. Both the transit and idling energy usage were calculated in order to provide a more accurate calculation of HDV energy usage at the port. The results of the calculations can be found in Table 20 which shows the HDV energy usage for those vehicles in transit around the port location in Btu/TEU (Starcrest Consulting Group, 2005).

Table 20. Port heavy-duty vehicle energy usage

HDV Energy Usage	
VMT/yr (1000)	4,405
mi/gal	6
gal/yr (1000)	735
MBtu (1000)	96
Btu/TEU (1000)	19

Table 21 shows the energy usage for idling HDV at the port location (Starcrest Consulting Group, 2005).

Table 21. Port heavy-duty vehicle energy usage from idling

HDV Idling Energy Use	
Idling hr/yr (1000)	1,909
Fuel Consumption (gal/hr)	1
gal/yr (1000)	1622107
Btu (1000)	211
Btu/TEU (1000)	41

The final energy calculation that needed to be done for the intermodal transfers was for the auxiliary engine usage during the hotelling of the ocean-going vessel.

Table 22 shows the results of the calculation as Btu/TEU.⁵

⁵ The numbers provided imply an over confidence on precision. This precision is addressed in the final case study results.

Table 22. Energy usage from roll-on/roll-off vessel auxiliary engine hotelling

Auxiliary Engine Power Output, kW					
Vessel Type	Hotelling kW	Hotelling Time (hr)	Btu/hr	Total Annual Btu	Btu/TEU
Ro/Ro	998	44	3406174	148849804	29

Using conceptually the same model as in the calculation of the intermodal transfer emissions, the energy for intermodal transfers is calculated using Equation 9.

$$\sum h \cdot k + q \cdot k + r \cdot k + s \cdot k$$

Equation 9. Intermodal transfer energy calculation

where h is the on-port rail switching energy usage; q is the roll-on / roll-off hotelling auxiliary engine energy usage; r is the HDV on-port transit energy usage; s is the HDV on-port idling energy usage; and k is a binary number (0 or 1) used to denote whether or not certain sources are being calculated within the equation. Table 23 shows the intermodal transfer energy usage that were calculated for use in the GIFT model.

Table 23. Intermodal transfer energy consumption

Intermodal Transfer	Btu/TEU
Ship To Rail	16397
Ship To Truck	60076
Truck To Rail	75462

4.7 Intermodal Transfer Time and Operating Cost Calculation

The transfer times and operating costs for intermodal transfers are a critical aspect of transportation modeling, but are even more important for freight modeling, since time and operating cost are often the primary attributes optimized when determining the best route.

Obtaining accurate time data was extremely difficult because accurate time-related data are proprietary information held by private carriers and not available for use in the public domain. Therefore, the best effort was made to provide the GIFT model with accurate intermodal transfer times and costs based on prior models that attempted to model similar activities.

4.7.1 Time Penalties for Intermodal Transfers

The intermodal transfer times were obtained from the an intermodal freight study conducted by the Midwest Regional University Transportation Center (Midwest Regional University Transportation Center, 2003). On average, a RORO vessel takes, depending on its load, two hours to unload and load freight. A transfer from truck to rail, again depending on the size of the train and the amount of freight being moved, can average two hours. These transfer times are noted in

Table 24 which shows the transfer times that are used in the GIFT model (Midwest Regional University Transportation Center, 2003).

Table 24. Transfer times per container

Transfer Times	Hour/TEU
Ship to/from Rail	2
Ship to/from Truck	2
Truck to/from Rail	2

4.7.2 Operating Cost Calculation

The intermodal transfer costs were determined using the data from the National Ports and Waterways Institute (2004). The report stated the port cost to be \$35/trailer and the local drayage cost to be \$100/trailer totaling \$135/trailer for intermodal transfers. In order to obtain the per TEU unit necessary, the data were divided in half since a trailer is an FEU and therefore two TEU. Table 25 shows the calculated transfer costs.

Table 25. Intermodal transfer costs per container

Transfer	Cost
Ship to Rail	\$67.50
Ship to Truck	\$67.50
Truck to Rail	\$67.50

4.8 Model Creation

The following sections provide a detailed description of how the GIFT model was created using the Network Analyst extension found in ArcGIS 9.1 (Falzarano et al., 2007). Before an intermodal network could be constructed, four shapefiles needed to be created. These included the following:

- Intermodal Transfer Node
- Highway-Rail Connection
- Highway-Waterway Connection
- Rail-Waterway Connection

Using ArcCatalog, shapefiles were created using the above terminology. The intermodal transfer node needed to be identified as a point shapefile and the three modal connections as polylines. These shapefiles were saved to a folder that contained all of the other shapefiles that were used in the GIFT model. Creating the shapefiles is essential because when using the editing tool in ArcMap there needs to be a “Target” noted when using the editing tool.

4.9 Connecting Artificial Transfer Nodes and Links

The editing tool provided by ArcMap provides the capability to create the necessary connectivity. The highway, rail, and waterway routes are three separate layers. When these

layers are placed into ArcMap they are layered one on top of the other and are therefore not an integrated network. The transfer facilities and port terminals are not connected geographically to other features (highway, rail, and waterway) within the network. Therefore, a network needed to be generated that connected the transfer facilities, port terminals, and three separate modes of freight transportation in order to create the intermodal network. Figure 8 demonstrates the problem that was encountered.

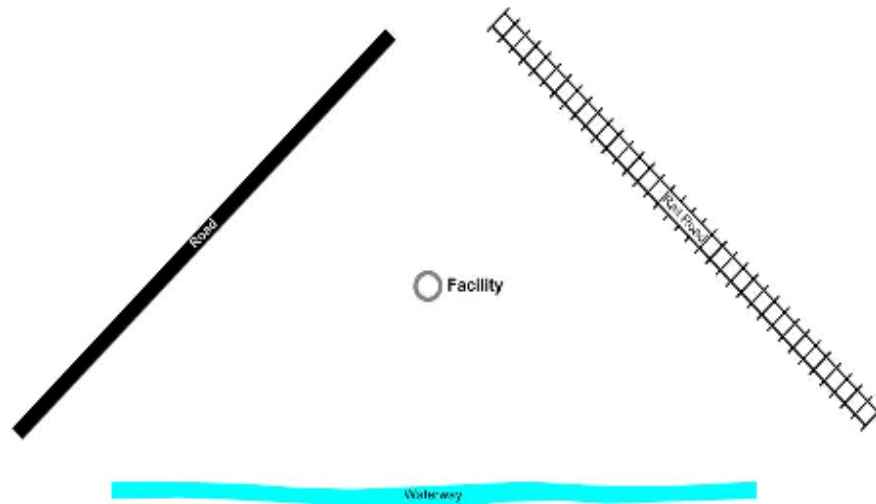


Figure 8. Disparate network connectivity

An approach was needed that provided the ability to transfer from one mode of transport to another mode only at appropriate facilities or terminals. The approach explained in this section was the best approach, given the original problem of connecting different modes of transport and attaching to the network custom environmental evaluators.

As seen in Figure 8, the facility is not connected with the other features nor are the other features connected to each other so therefore it was necessary to ensure that if a modal transfer was to take place the transfer happen only at or near the appropriate facility or terminal. In Figure 8, all of the features seen are the original features. Figure 9 is the representation of the network connectivity with the integration of artificial nodes and links.

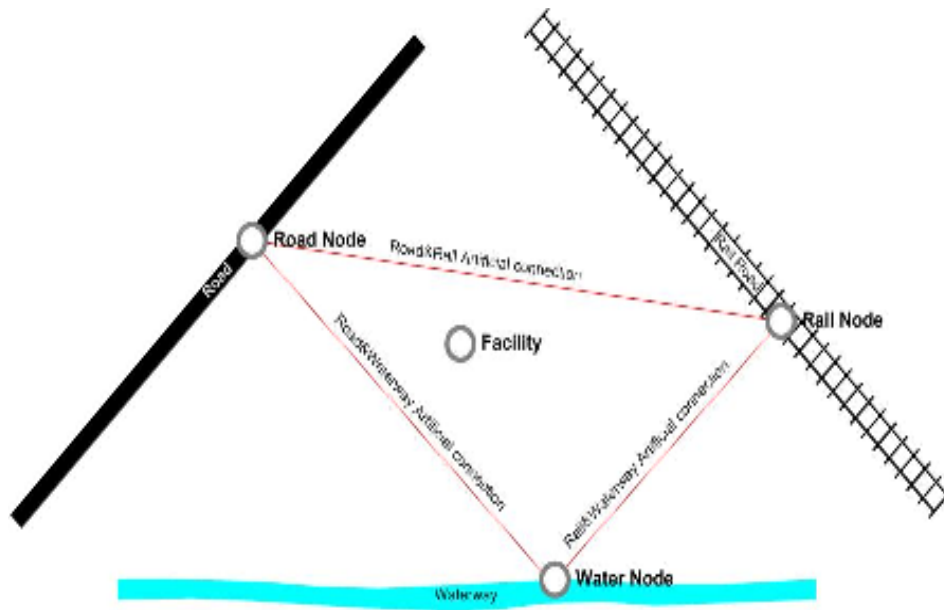


Figure 9. Intermodal network representation

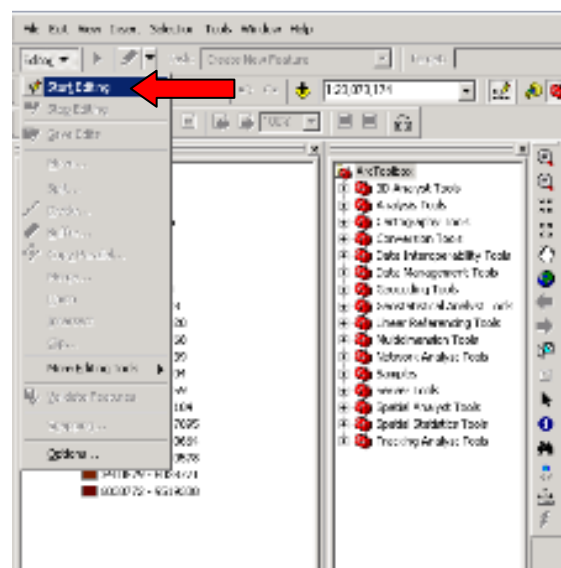
As seen in Figure 9, four new features have been created to meet the new set of requirements. The four new features are:

- Road and Rail Artificial connection
- Road and Waterway Artificial connection
- Rail and Waterway Artificial connection
- Intermodal Transfer Nodes (Road, Rail, and Waterway nodes)

The road and rail artificial connection, road and waterway artificial connection, and the rail and waterway artificial connection are line shapefiles. The road node, rail node, and waterway node are all the same node feature identified as “Intermodal Transfer Nodes” and were saved as a point shapefile.

A triangular artificial network was created around the facilities and/or terminals for transfers from one mode of freight transport to another mode. This type of connectivity simulates the facility or terminal participating in the network with the movement of freight between the different modes. The new node feature created acts as a point of transfer from one mode to another mode of transport in the network. The line features connecting the nodes facilitates the

transfers within the network dataset. The artificial features are the link between the original features which allows for a holistic freight transportation network to be created.



After applying the necessary rules and tolerances to the snapping environment, new features were created. The first feature to be created was the “Intermodal Transfer Points”, which needed to be the feature highlighted in the “Target” box located in the Editor toolbar as shown in Figure 12. The new points were created at the endpoints of the three (highway, rail, short-sea) transport modes or two (truck, rail) transport modes since this was the policy set for the snapping environment. For the GIFT model, great effort was taken to create the intermodal linkages at points where actual freight transfers would take place.

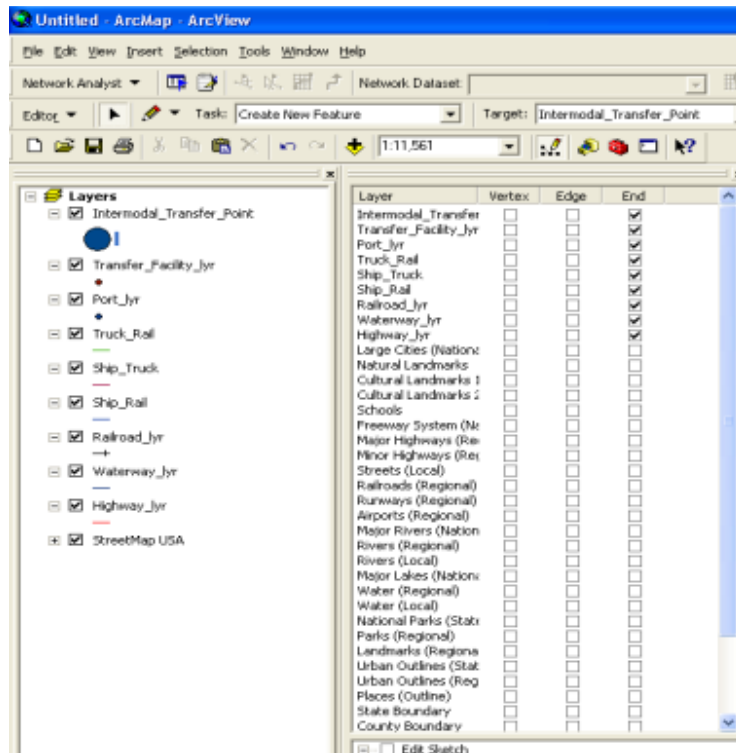


Figure 11. Setting the snapping policy

After the three (or two) intermodal transfer points were placed in the network, the artificial connections were created linking the different modes of transport. In the editor toolbar, it was necessary to change the “Target” drop-down selection to reflect the feature that was being created (road-rail connection, rail-waterway connection, etc...). A depiction of this is provided in Figure 12.

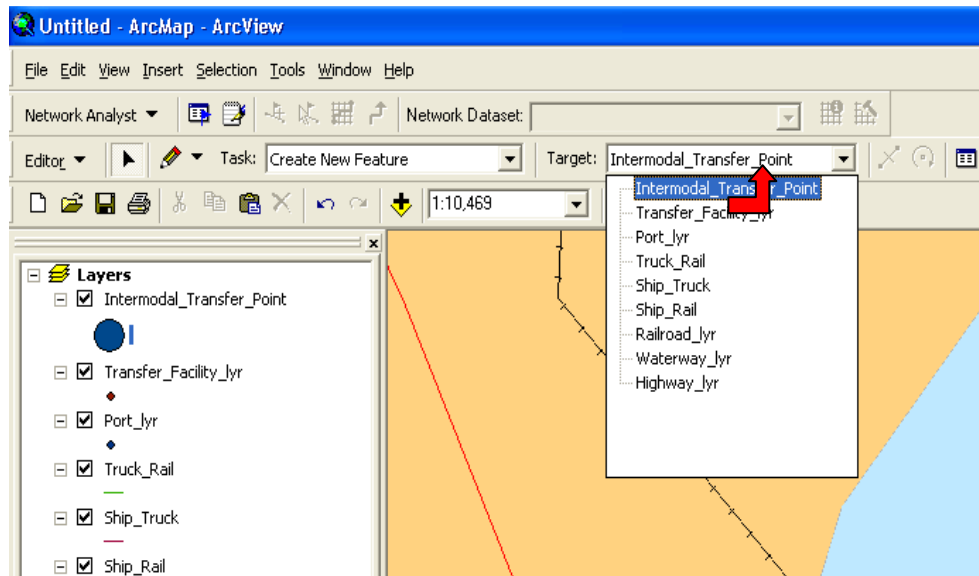


Figure 12. Setting the target within the editing session

After connecting the artificial nodes between the two different modes of transport, the ArcMap editing sketch was finished and the process continued until all of the necessary connections were constructed. Once all of the editing was complete, the edits were saved, and the process of preparing the data for building the network was started.

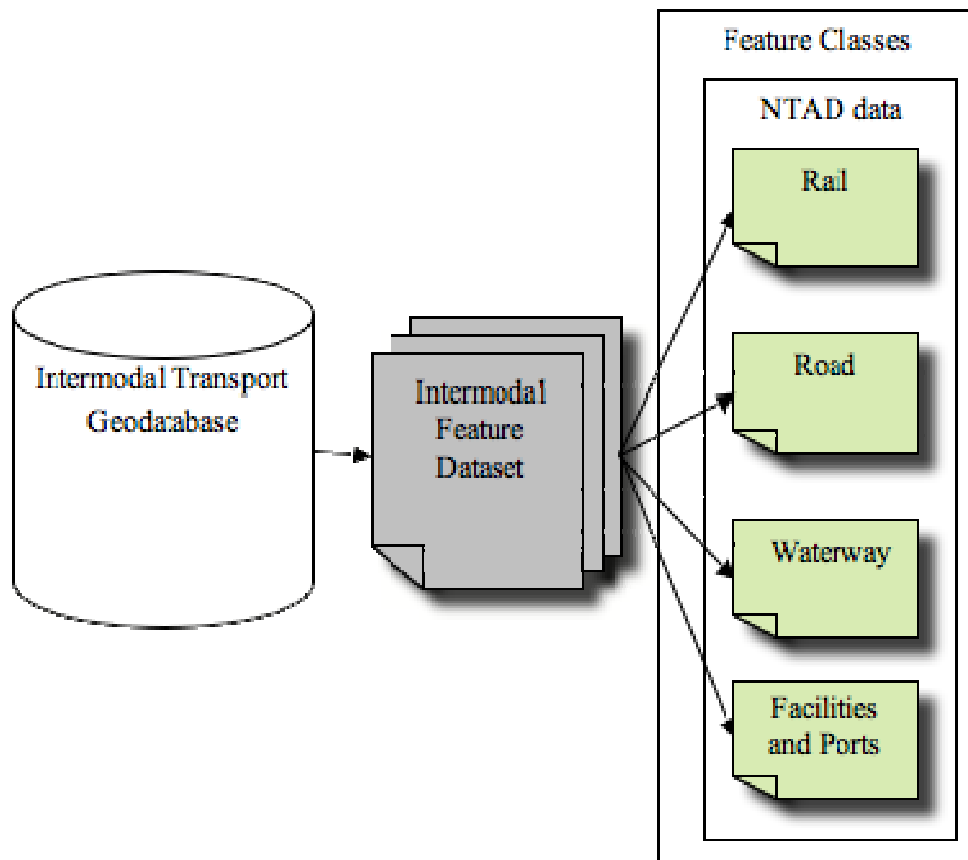


Figure 13. Elements composing the network dataset

The data had to be in a particular format in order to create a network dataset using the necessary features within ArcGIS. Figure 14 shows the first phase of the process to begin building a network dataset. In order to create the intermodal feature dataset, a Personal Geodatabase was created. Once a personal geodatabase was created, it was necessary to create a feature dataset which is shown in Figure 15. A name was created for the feature dataset and a coordinate system was defined, shown in Figure 16. The coordinate system that was chosen corresponded with the coordinate system that was used by the data in the National Transportation Atlas Database (NTAD).

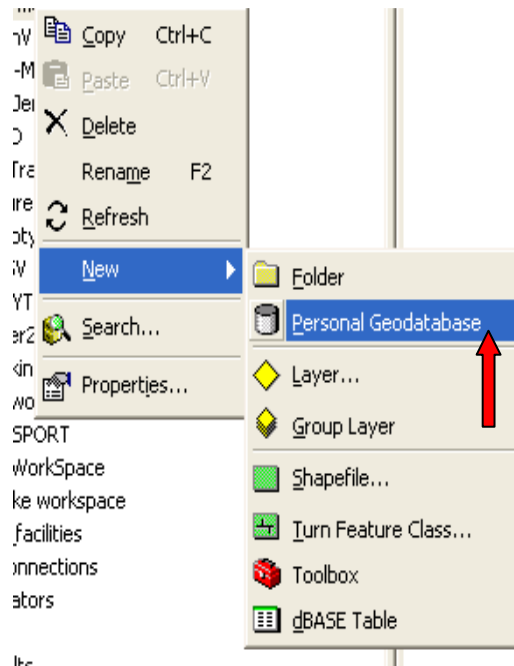


Figure 14. Creation of a geodatabase

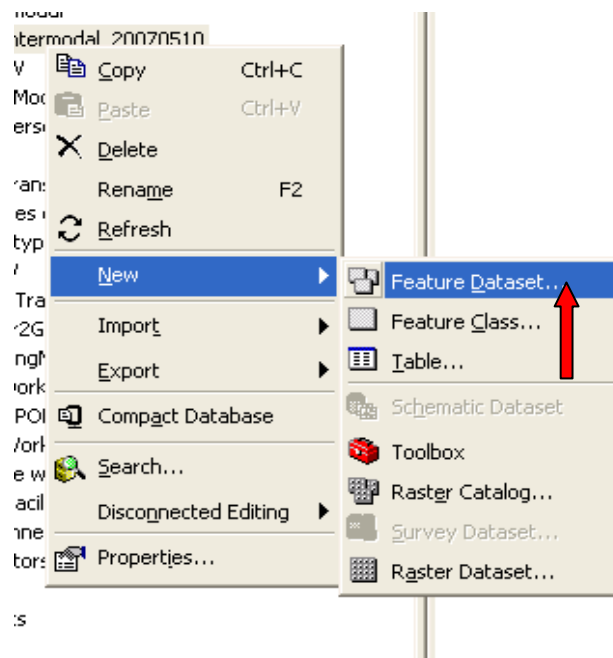


Figure 15. Creation of a feature dataset

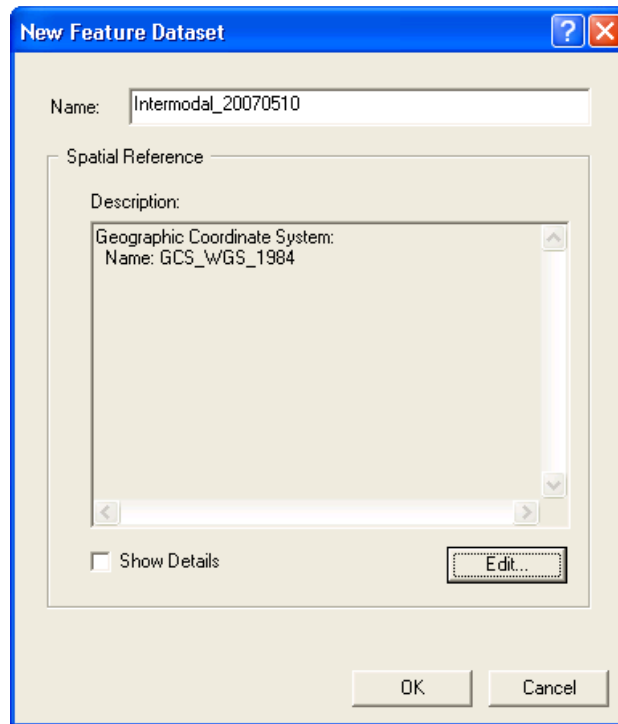


Figure 16. Naming and selecting the coordinate system

Once a feature dataset had been created, the dataset was populated with the necessary data that were to be included in the intermodal network. The process of populating the data for the database is shown in Figure 17 and Figure 18. The data used in the GIFT model included network data from the National Transportation Atlas Database. The map background was loaded from the ESRI StreetMap file.

- Highway Network (NTAD)
- Rail Network (NTAD)
- Waterway Network (NTAD)
- Port Terminals (NTAD)
- Transfer Facilities (NTAD)
- “Artificial” Intermodal Transfer Nodes
- “Artificial” Intermodal Connection Links

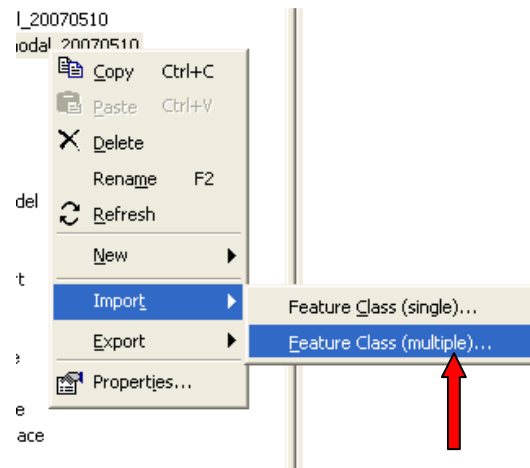


Figure 17. Importing feature classes into the feature dataset

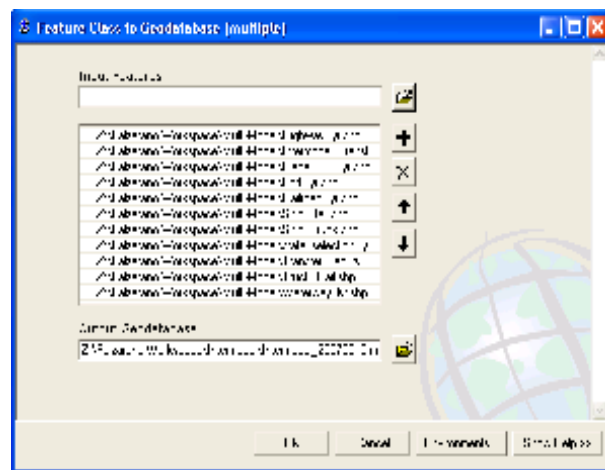


Figure 18. Selection of feature classes for feature dataset

4.10 Constructing the Network Dataset

Once the files were imported into the new feature dataset, the building of the network dataset could be started, as shown in Figure 19. First, the network dataset was named. Next, there was a determination of what feature classes were to be included in the intermodal network, as shown in Figure 20.

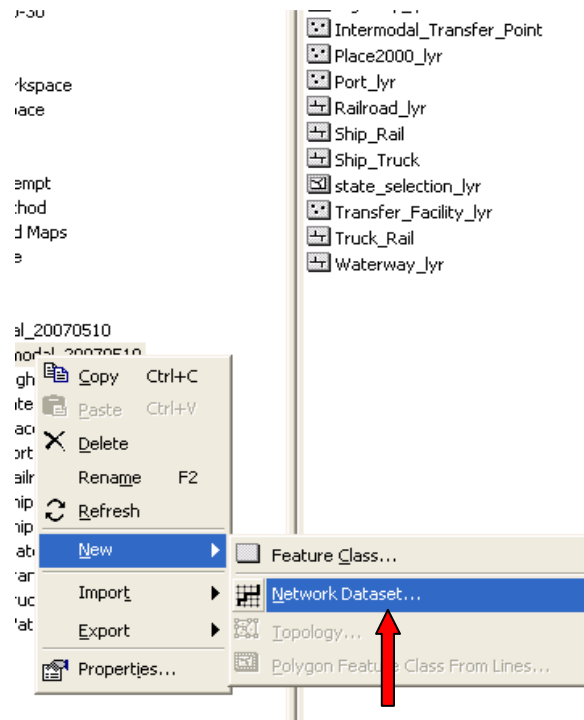


Figure 19. Creation of a network dataset

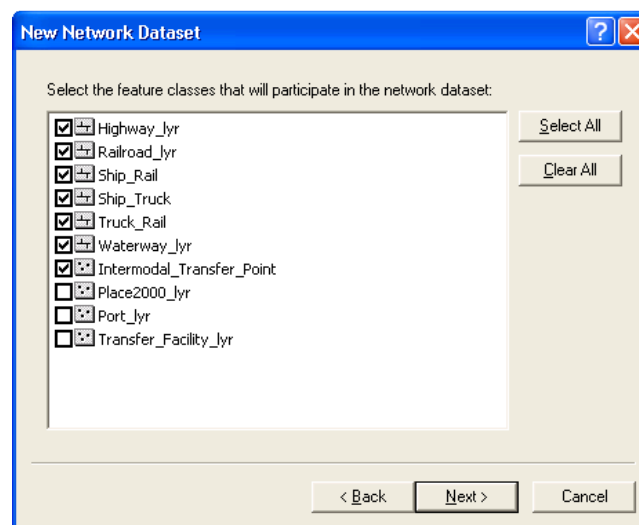


Figure 20. Selecting feature classes to participate in network dataset

After the features that would be participating in the network dataset were chosen, connectivity policies were input in order to connect each of the features in the network. This step is shown in Figure 21. The hierarchical structure of the GIFT model was set up such that three grouped

columns existed in the network. The model is grouped such that road is first, rail is second, and waterway is third. The intermodal transfer point is instructed to honor all three of the different modes of transport. Since the intermodal transfer point honors all three modes, the assignment of connectivity for the “artificial” connections is trivial. The element that determines whether an intermodal transfer takes place was the existence of the polyline linking the modes. If a polyline did not exist, then the transfer would not take place.

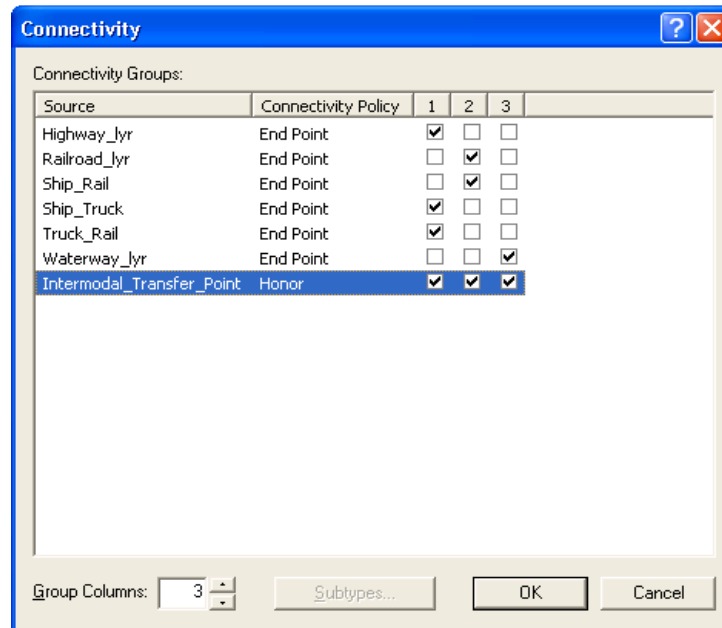


Figure 21. Setting the network connectivity policy

The next two prompts inquire about elevation data and global turns. For the purpose of the GIFT model the elevation data were left unchanged but global turns were honored in the network. The next important step required the adjustment of the evaluators in the network dataset. The GIFT network uses the standard distance evaluator that the Network Analyst extension provides but also uses custom evaluators (Hawker et al., 2007).

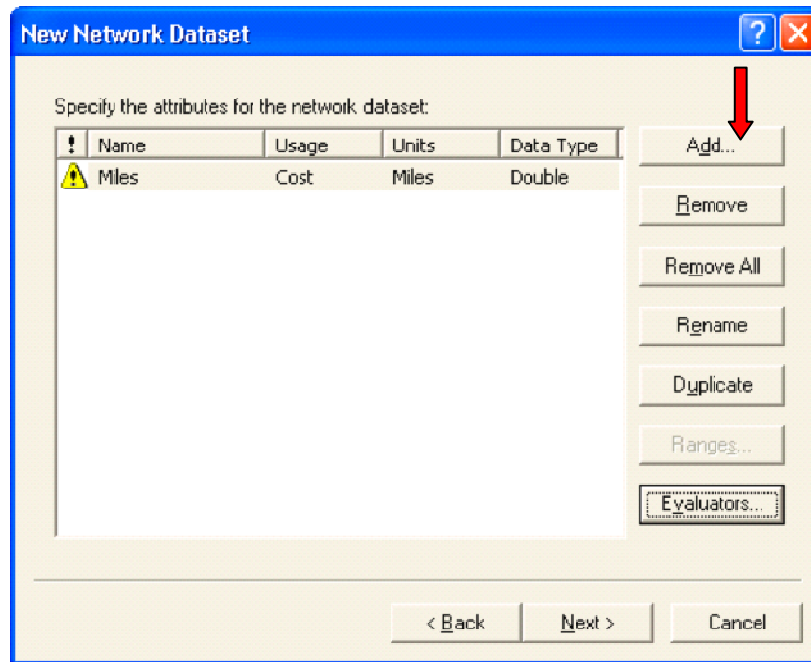


Figure 22. Adding new attributes

The new evaluators needed to be added to the network dataset. The addition of the evaluators is shown in Figure 22. Figure 23 shows the prompt which allows a user to name the attribute, define the usage type, and set the unit of measurement. Once all of the new attributes were added to the network dataset, values were added to the attributes so that the network would be able to correctly calculate the new attributes. The setting up of the network dataset properties is shown in Figure 24 and Figure 25.

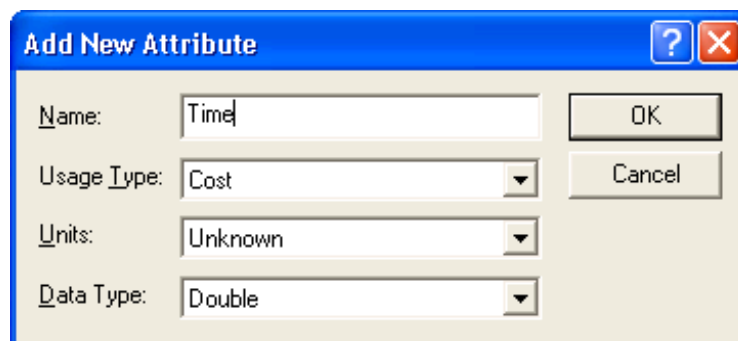


Figure 23. Defining the new attribute

Once the appropriate evaluator value was selected from the drop-down box in the column marked “Type”, the value for that field was automatically determined, since the evaluator type has a pre-determined value based on variables input by the user into the user interface (Hawker et al., 2007). This process was repeated for all of the attributes that had been added to the network. For the “Miles” attribute, it should be noted that for the purpose of the GIFT model, the transfer links that connect the various modes of transport have an assumed value of zero, as shown in Figure 26.

	To-From	Edge	Field	LENGTH
Railroad_lyr	From-To	Edge	Constant	0
Ship_Rail	From-To	Edge	Constant	0
Ship_Rail	To-From	Edge	Constant	0
Ship_Truck	From-To	Edge	Constant	0
Ship_Truck	To-From	Edge	Constant	0
Truck_Rail	From-To	Edge	Constant	0
Truck_Rail	To-From	Edge	Constant	0
Waterway_lyr	From-To	Edge	Field	LENGTH1

Figure 26. Assigning transfer link distance

After values were assigned to all of the attributes, the evaluator process was complete. The remaining steps finalized the creation of directions for the network. It should be noted that establishing driving directions is not mandatory to create a functional network, the activity is optional. Each mode has an attribute which distinguishes it, typically a name. Network Analyst identifies this attribute and uses it when creating a set of directions for your selected route. Upon completion of this task, the network was ready to be built. Once completed, the network dataset was placed into the personal geodatabase as shown in Figure 27.

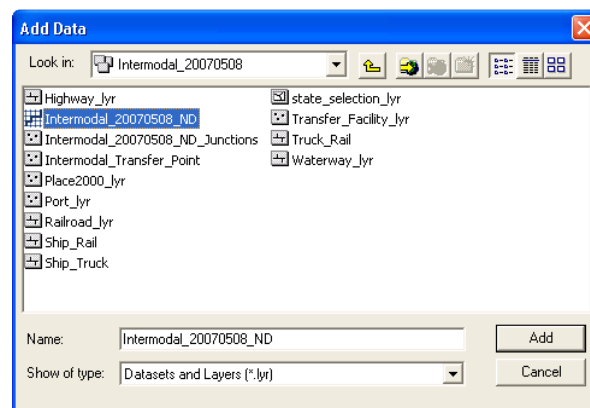


Figure 27. Accessing created network dataset

In order to use the network dataset, ArcMap needed to be started and the network dataset file needed to be uploaded to the map as shown in Figure 27. Once the network dataset was loaded onto the map, the network could be used with the Network Analyst extension. The visual representation of the network is shown in Figure 28.

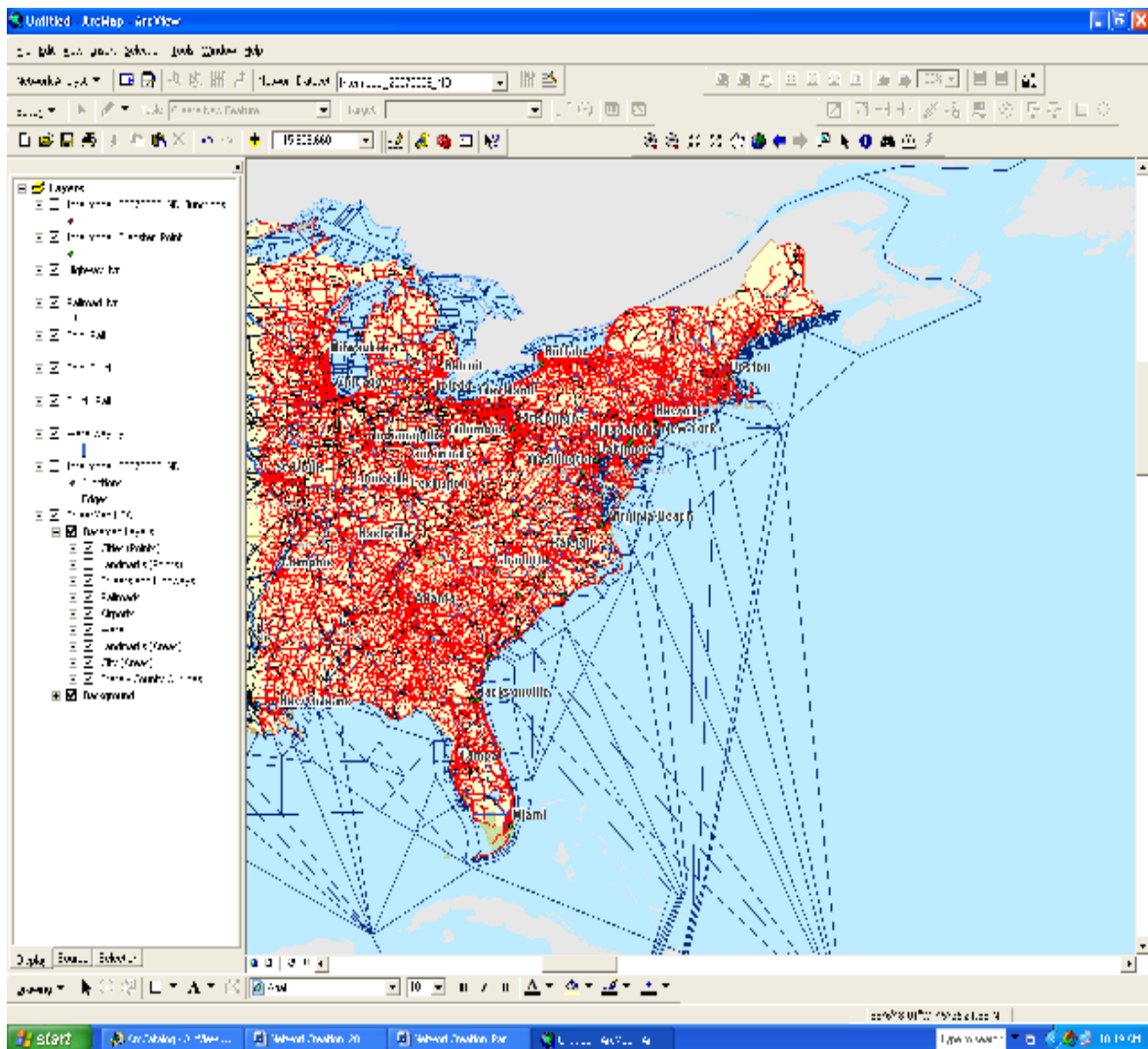


Figure 28. Display of network dataset

4.11 Application

With all of the necessary attributes added to the network and the network dataset built, the network could now be used to analyze intermodal freight movement. The GIFT model features a

user interface that allows users to input their own data in order to run multiple analyses and explore their own tradeoffs. Within ArcMap, a button was created, as shown in Figure 29, that allows users access to the user interface shown in Figure 30 (Hawker et al., 2007).

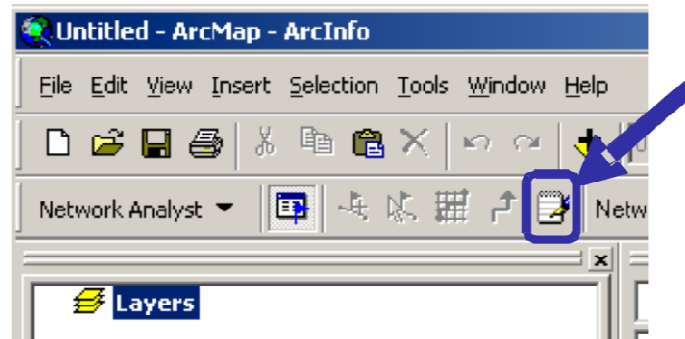


Figure 29. Accessing the user interface

The button provides access to a user interface that allows users to create and save sets of data. Data input into the user interface can be accessed by the Network Analyst extension. The data are used to find optimal routes based on the attribute being optimized as determined by the user. Figure 31 demonstrates the ability for users to create, name, and save their datasets. Figure 32 shows the ability to re-use old saved datasets in order to explore the output of different datasets. Figure 33 demonstrates the ability for the user to select the set of saved data that they would like to use to conduct their analysis.

Manage Analysis Values

Manage Transportation Analysis Values

Network Analyst will currently use this set: **Baseline**

Name/Description of currently displayed values: Click down arrow to show all sets

Baseline

Click any cell to edit it

Transport_Mode	CO2	CO	NOx	PM10	SOx	VOC
Truck	1000.79	1.637	6.863	0.1185	0.22169	0.339
Rail	143.602	0.3947	2.8067	0.0665	0.0319	0.1368
Ship	292.83	1.3982	8.0128	0.2458	3.9564	0.3112
Ship_Rail	57715.1	552.07	2589.34	154.43	833.43	157.53
Ship_Truck	57033.3	651.2	2939.33	159.3	823.58	172.32
Truck_Rail	2003.14	293.85	1520.38	44.57	28.93	81.85

gm/TEU-mile or gm/TEU for transfers

Operating Cost

Transport_Mode	Cost
Truck	1.7
Rail	1.6
Ship	1.2
Ship_Rail	50
Ship_Truck	50
Truck_Rail	25

\$/TEU-Mile or \$/TEU for transfers

Energy Rate

Transport_Mode	Energy_Rate
Truck	12854
Rail	1850
Ship	3400
Ship_Rail	500
Ship_Truck	500
Truck_Rail	500

BTU/TEU-Mile or BTU/TEU for transfers

Speeds

Transport_Mode	Speed
Truck	50
Rail	35
Ship	25

Statute miles/hour

Transfer Times

Transport_Mode	Time
Ship_Rail	12
Ship_Truck	16
Truck_Rail	12

Hours

Set Network Analyst Set
Set the current set as Network Analyst's analysis value set

Manage Sets
View and remove named sets, or modify (Opens new window)

Update
Update values in currently selected set

New
Save values in a new named value set

Cancel
Cancel changes and revert to previous working set values

Done
Done managing analysis values (Remember to set this as Network Analyst Set if you want to use these values)

Figure 30. GIFT user interface

Enter New Set Name

Enter a name or description for the new set of analysis values

Cost values reflecting waterway rebates and truck tax

Number of characters: 53
(Up to 100 characters)

OK Cancel

Figure 31. Creation of a new set of values for analysis

After data were input to the interface, layer properties were set (Figure 34) which allows the user to determine the attributes that will be accumulated during the analysis. Next, it is necessary for to select the impedance (Figure 35). The attribute selected as the impedance will be the attribute that is optimized with the solver is initiated. As is normal practice with the Network Analyst extension, points were selected to signify the origin and destination, and the solve button was selected to determine the optimal route for freight to navigate based on the optimized attribute.

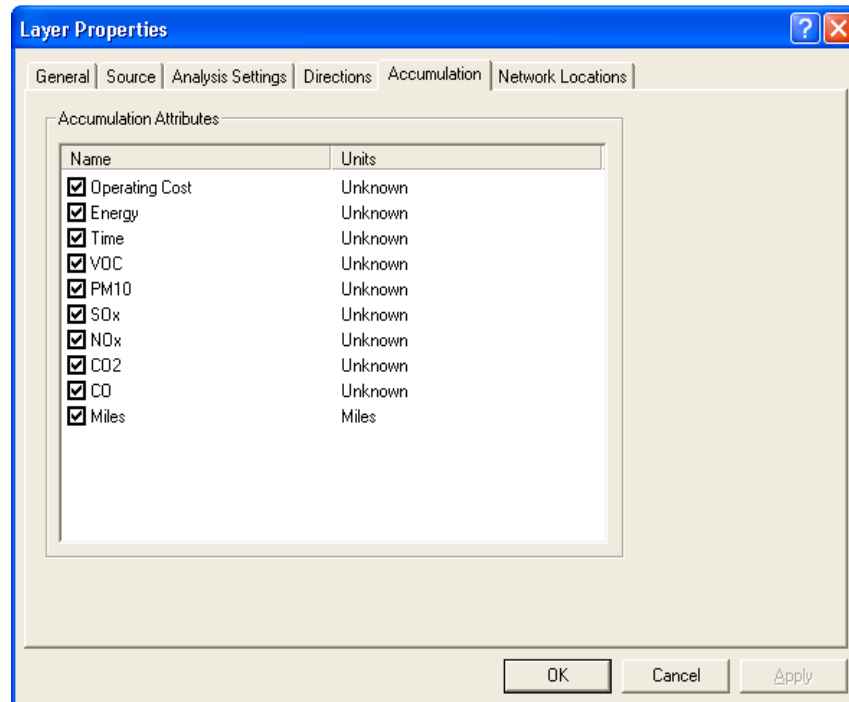


Figure 34. Selection of attributes to be accumulated

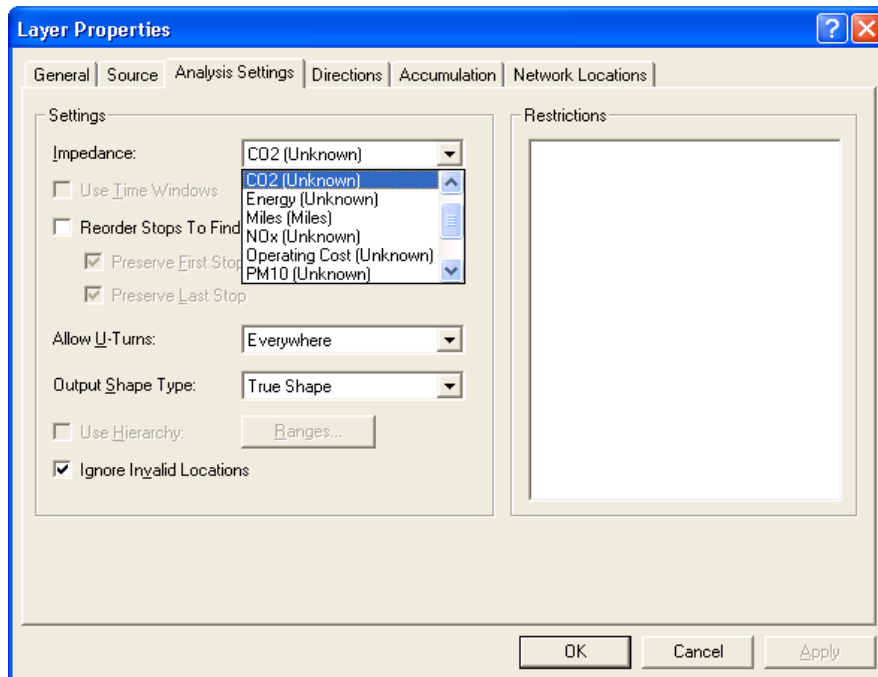


Figure 35. Selection of optimized attribute

The Network Analyst extension allows for a properties window, shown in Figure 36, to be selected when the user right-clicks on the highlighted route. Also, directions can be accessed for the optimal route that has been generated as shown in Figure 37.

Attribute	Value
ObjectID	5
Name	NY/NJ - Jacksonville
FirstStopID	1
LastStopID	2
StopCount	2
StartTime	<Null>
EndTime	<Null>
Total_CO2	272891.360833
Total_Operating Cost	1398.455657
Total_Energy	3611117.480262
Total_Time	38.064148
Total_VOC	309.459498
Total_PM10	153.838878
Total_SOx	68.310417
Total_NOx	5877.770124
Total_CO	957.546287
Total_Miles	945.949502

Figure 36. Calculated attributes for selected route

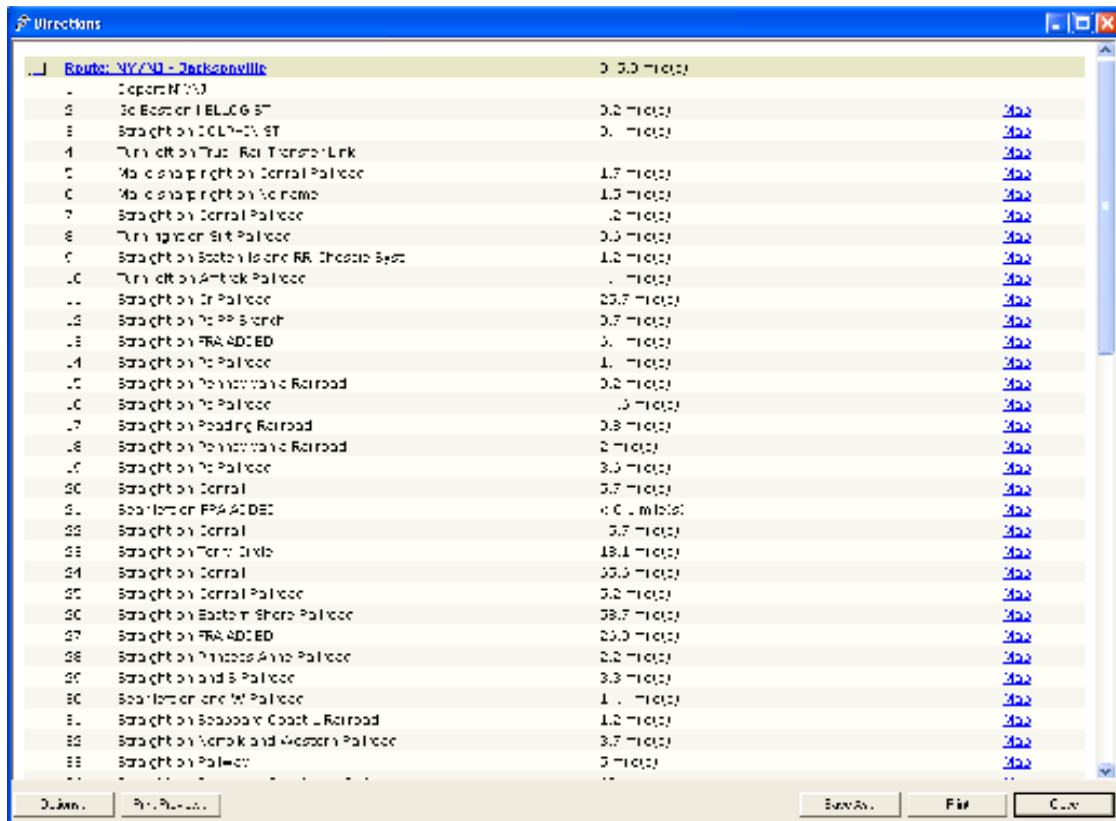


Figure 37. Directions for selected route

The creation of the GIFT model has opened up many opportunities for research. Currently the model views freight only on the per TEU basis as opposed to being a cargo flow model. It is possible to run the model multiple times to attempt to simulate a cargo flow model, but the current model is built to simulate the movement of only one TEU at a time. The construction of the costs in the model is also being evaluated. The model provides policy analysts with an opportunity to evaluate freight movement in a new and exciting way. No longer are analysts constrained with only least time and least cost routing. GIFT allows an analyst the ability to analyze the environmental impacts of freight movements and also analyze the impacts of different policies and new technologies. It is feasible to run a scenario in the model that simulates the effect of a congestion mitigation policy or the introduction of CO₂ reducing technologies. Given this flexibility, the GIFT model provides significant opportunities to analysts. The next section will provide a case study application of the GIFT model.

5. Case Study Analysis

5.1 Overview of Cases

To demonstrate the use of the GIFT model, three case studies were conducted. The case studies focused on route selections of an origin to a destination along the US Eastern Seaboard. The case studies are used to exercise the model to investigate intermodal route optimizations based on environmental and other objective functions and to explore the tradeoffs associated with the different optimizations.

The first case analyzed was one in which the origin was open water (OW) about 90 miles off of the coast of New York City (NYC) and the destination was Miami, FL. The second case was another long-haul journey in which the origin was a hypothetical distribution center located in Rochester, NY and the destination was Jacksonville, FL. The third case was a short-haul route with an origin located in the northern New Jersey about 20 miles outside of New York City and the destination was Boston, MA. The case studies are shown in Table 26.

Table 26. Origins and destinations for case studies

Case No.	Origin	Destination
I	NYC Open Water (OW)	Miami, FL
II	Rochester, NY	Jacksonville, FL
III	NY/NJ Metro	Boston Metro

5.2 Case Study Data

The data used for the case studies were drawn from a variety of sources. The data included both segment attributes and intermodal transfer costs as shown in Table 27 and Table 28 respectively. Emissions and energy use segment data for each mode were obtained using a combination of the Total Energy and Emissions Analysis for Marine Systems (TEAMS) model and the most recent

Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET v.1.7) model (Burnham, Wang, and Wu, 2006; Winebrake, Corbett, and Meyer, 2007). With the exception of CO₂, tailpipe and stack emissions were extracted for all pollutants.

Since CO₂ is a global pollutant, and geospatial resolution is not important, total fuel-cycle emissions were used, which included carbon emissions associated with processing and delivering the fuel. The use of total fuel-cycle emissions allowed for the comparison of carbon emissions in total from the use of different fuels and fuel blends (e.g., biodiesel fuels). The emissions data for the intermodal transfers were derived using the Port of Los Angeles Baseline Air Emissions Inventory – 2001 report that was released in July 2005, and included emissions and activity estimates for a variety of port handling and transfer equipment (Starcrest Consulting Group, 2005).

Modal operating costs in Table 27 were shown for each segment and derived from the Four Corridor Case Studies of Short-Sea Shipping Services prepared by Global Insight (2006). Intermodal transfer costs were obtained from a report on short-sea shipping and are a sum of the port cost and the local drayage costs outlined in that report (Midwest Regional University Transportation Center, 2003).

Finally, intermodal transfer time penalties for ship transfers were taken from the Twin Ports Intermodal Freight Terminal Study (Midwest Regional University Transportation Center, 2003). The truck – rail transfer is an estimation using data taken from the LA/Long Beach Inventory rail switching times (Middendorf, 1998; National Ports and Waterways Institute, 2004). Final intermodal transfer costs are shown in Table 28.

Table 27. Data for transport modes for case studies

Mode of Transport	Cost (\$/TEU-mi)	Energy (Btu/TEU-mi)	CO ₂ (g/TEU-mi)	PM ₁₀ (g/TEU-mi)	SO _x (g/TEU-mi)
Truck	0.87	10704	1001	0.12	0.22
Rail	0.55	2590	201	0.09	0.04
Ship	0.50	13040	1094	0.98	3.33

Table 28. Data for intermodal transfer penalties for case studies

Type of Transfer	Time (hr/TEU)	Cost (\$/TEU)	Energy (Btu/TEU)	CO ₂ (g/TEU)	PM ₁₀ (g/TEU)	SO _x (g/TEU)
Ship to/from Rail	2	67.50	16397	360	20	11
Ship to/from Truck	2	67.50	60076	380	22	11
Truck to/from Rail	2	67.50	75462	407	22	8

5.3 Case Study I: New York City OW to Miami, FL

The first case study illustrated a container on a vessel in open water about 90 miles outside the port of New York. The ultimate destination for the container was Miami, FL. GIFT was used to run an intermodal route optimization based on three different objectives: minimize CO₂, minimize cost, and minimize time. Results from the analysis are shown in Table 29 and Figure 38 shows the map with the three routes that were selected. Also shown in Table 29 are the values of other key attributes that are not being optimized but are calculated such as SO_x, PM₁₀, energy, and distance.

The results of Case Study I clearly indicate three separate modal preferences for each of the objectives. To minimize CO₂, the mode of choice is predominantly rail; to minimize cost, the choice is predominantly ship; and to minimize time, the choice is predominantly truck. The results clearly identify the existence of tradeoffs between lowering CO₂ emissions and reduction time of travel. Although the least CO₂ route emits about a third of the CO₂ from the least time route, the journey lasts about 36 hours longer. Additionally, the least time route emits over four times the amount of CO₂ and costs \$300 more than the least CO₂ route.

Table 29. Results for Case Study I

Open Water - Miami, FL Route Analysis							
	CO ₂ (MT)	SO _x (kg)	PM ₁₀ (kg)	Energy (mmBtu)	Cost (\$)	Time (hr)	Distance (mi)
Min. CO ₂	0.4	0.4	0.3	5	925	61	1432
Min. Cost	1.3	3.9	1.2	15	668	49	1185
Min. Time	1.4	0.6	0.3	15	1226	25	1376



Figure 38. Routes selected for Case Study I

5.4 Case Study II: Rochester, NY to Jacksonville, FL

The second case study was a common representation for many domestic shippers. Here, the container began its journey at a land-based local distribution center in Rochester, NY (origin) and traveled to Jacksonville, FL (destination). Results from the analysis are shown in Table 30 and Figure 39 shows the map with the three selected routes.

The results once again depict the tradeoffs associated with different modal choices. Here, both the least CO₂ route and the least cost route are the same—predominantly rail, with some movement by truck to an intermodal truck-rail transfer facility near Buffalo, NY, and once again back to truck near Jacksonville for final delivery (the short-haul). An important point to note is that given the lack of an adequate transfer facility in Rochester, the freight had to make an initial journey by truck to the transfer facility in Buffalo where it was then transferred to rail. A decision maker could, using the GIFT model, place a transfer facility in Rochester and explore the tradeoffs associated with having this type of facility in the Rochester area, rather than having freight travel first to Buffalo before being transferred to a different mode.

This type of hypothetical activity can help transportation planners and policymakers when determining the need for appropriate intermodal freight facilities in their respective area. This example also illustrates opportunities to modify the network by adding or subtracting nodes or segments to examine the impact modifications would have on the overall intermodal route logistics. The emissions and economic benefits associated with the least-CO₂ route must be considered in light of the additional 37 hours it takes to deliver this shipment.

Table 30. Results for Case Study II

Rochester, NY - Jacksonville, FL Route Analysis							
Optimization	CO ₂ (MT)	SO _x (kg)	PM ₁₀ (kg)	Energy (mmBtu)	Cost (\$)	Time (hr)	Distance (mi)
Min. CO ₂	0.3	.08	0.2	4	866	54	1278
Min. Cost	0.3	.08	0.2	4	866	54	1278
Min. Time	1.2	0.3	0.2	13	1007	17	1157



Figure 39. Routes selected for Case Study II

5.5 Case Study III: NY/NJ Metro to Boston, MA Metro

The third case study looked at a container originating about 15 miles west of the Newark, NJ airport destined for Boston, MA. Results from this analysis are shown in Table 31 and the map displaying the different routes is shown in Figure 40. The route that minimizes time and cost used predominantly trucking during its journey, with the only difference being a slight diversion in the Connecticut area to reduce distance (directly related to cost) by moving from a slightly longer but quicker highway to a shorter but slower road. However, the least CO₂ route uses rail

and makes two intermodal switches. With a short-haul journey, such as the one shown in this case study, freight tends to move by truck since the extra cost of using the truck is less than the added costs associated with an intermodal transfer.

Table 31. Results for Case Study III

New York/New Jersey - Boston Route Analysis							
Optimization	CO ₂ (MT)	SO _x (kg)	PM ₁₀ (kg)	Energy (mmBtu)	Cost (\$)	Time (hr)	Distance (mi)
Least CO ₂	0.1	0.1	0.1	1	299	15	286
Least Cost	0.3	0.1	0.1	3	213	5	245
Least Time	0.3	0.1	0.1	3	220	4	253



Figure 40. Routes selected for Case Study III

Although the intention of the case study analysis was to demonstrate the model, a quick look at the resulting tables generates several interesting insights. First, notice the significant advantage that trucking presents for time-of-delivery, dominating routes in all three cases where time was an objective. The time-of-delivery advantage is often accompanied with higher costs and emissions (especially for long-haul trips). Second, observe that there are specific emissions tradeoffs associated with some route selections. For example, in Case Study III, the least-CO₂ route also represented the higher emissions of PM₁₀. The result is driven by emissions occurring at the intermodal transfer facilities. Therefore, particularly for short-haul activity, one must consider the impacts of intermodal transfers on emissions and energy consumption.

The generalization of these results is difficult given that they are dependent on the origin and destination points that have been selected. Future work may be done to test a set of origin-destination pairs that have controlled characteristics for a more systematic analysis. Caution should be taken when approaching the results given the lack of appropriate sensitivity analysis that might be associated with a full-blown case study of freight movement along the US Eastern Seaboard. Future work may also include integrated parametric sensitivity analyses that conform to the probability distributions expected for the data currently being utilized in the model. Nevertheless, the demonstration indicates the rich types of analyses that can be conducted using the GIFT model.

6. Policy Implications

6.1 Current Situation

As noted in the prior section demonstrating the three case studies, a policymaker can use the GIFT model to be able to examine policies that would encourage the use of transportation modes that better balance the concerns of time, cost, energy consumption, greenhouse gas emissions, and airborne pollutants that impact health. Although intermodal freight transport has shown how it can assist in providing a more sustainable alternative to current freight movement practices, intermodal freight transport has encountered a variety of issues within the US including:

- Insufficient cooperation between Federal and state governments
- Division of different departments within the US Department of Transportation
- Fragmentation of freight terminals and facilities
- Absence of acceptance by the freight industry
- Lack of understanding of the complete supply chain

Government, at all levels, needs to be involved in developing policy to promote more efficient freight transportation in the US in order to reduce the externalities and social costs associated with such goods movement. The impacts of freight transportation have become increasingly more noticeable and the issues have begun to show up on governmental agendas. In 1995 the US Department of Transportation proposed an initiative that would help reorganize the organization and improve collaboration to enhance intermodal transportation, both for freight and passengers. The proposal failed to gain the approval of Congress.

The Office of Intermodalism, which was established in 2004 within the Office of the Secretary within the US Department of Transportation, focused primary on the research aspect of freight transport and not policy. While the research is important in order to uncover new and more innovative approaches to efficient freight transportation, the balance between research and policy is what provides the biggest hurdle in making intermodal freight transport more common practice.

The federal government has been making progress in trying to get intermodalism pushed further into the mainstream. The problem is that much of their efforts have been to push the burden to state and local governments to work on updating, and in some cases creating, new intermodal infrastructure. Initiatives such as these require large amounts of investment, and funding is something that many state and local governments have very little of. Much of the funding that states count on comes predominately from the Federal government. So, to ask state and local governments to provide funding for intermodal projects would be asking for far too much. Although the state and local governments may not be able to provide all of the upfront costs for an intermodal project, it is possible for cost-sharing to take place between the Federal, state, and local governments. This type of activity would distribute the financial burden and promote a higher level of cooperation between the different levels of government to improve the efficiency of freight transportation.

Difficulties arise not only across the different levels of government but also within the Federal government itself. The US Department of Transportation is composed of a variety of agencies including the Federal Highway Administration, the Federal Railway Administration, the Federal Aviation Administration, and the Federal Maritime Administration. Each of these agencies has their own agenda and their own budget, which they aggressively defend every fiscal year. The goal of each of the agencies is to improve and promote their designated mode of transport and therefore it becomes difficult to discuss intermodal transport, which is focused on creating a balance between the different modes of transport. The balance would result in the decrease in highway usage, increases in the usage of rail and waterway transport, and ultimately an increase in the budgets of the Federal Railway Administration and the Maritime Administration. Obtaining buy-in from the different agencies becomes difficult when the result of an action will have a direct benefit or detriment to another agency. Until the fragmentation of agencies within the US Department of Transportation can be sorted out, a comprehensive intermodal freight policy will be very difficult to construct and implement.

On a micro-scale, when one looks at either ports or freight terminals, they see a puzzle filled with a variety of pieces that often fail to fit together to create a holistic picture. For example, it is not uncommon to find different private operators all operating at the same port. You may have one company running security, another operating the cranes and forklifts, and another company

overseeing the entire operation. This type of arrangement creates an assortment of issues, but the primary issue deals with organization. With such an array of operators, all having their own agenda, organizing for intermodal transport is very challenging. The key component to successful intermodal transfer is logistics, and in order to have the high-level logistics necessary for intermodal freight transport, it is necessary to have all parties involved organized with clear pathways of communication.

Building off of the fragmentation at the ports and freight terminals, the freight industry itself has been reluctant to fully embrace the intermodal concept, at least until recently. Large freight companies, such as CSX and Schneider, have been more accommodating to improving their freight management to incorporate the increased use of intermodal transfers. Much of their improvement can be attributed to higher fuel costs and growing congestion concerns, but nonetheless the increased usage of intermodal freight transport by larger companies will soon impact the logistics decisions of smaller companies. Companies such as Hewlett Packard and Wal-Mart have been looking at new approaches to the supply chain management to incorporate more sustainable principles. Professional organizations such as the Council of Supply Chain Management Professionals and the International Warehouse Logistics Association have been discussing ways to improve the supply chain to promote a healthier planet. Even though the freight shipping industry may not be leading the way when it comes to intermodal freight transport, a number of other entities are filling in the gaps to become more proactive.

Part of the hesitation by the freight industry in encouraging intermodal freight transport is rooted in time and money. This is not to say that companies in the freight industry do not attempt to promote the more sustainable movement of freight. Many companies and professional organizations, as noted above, are taking the initiative to pursue environmentally sustainable freight transport for their goods. As companies begin to practice intermodal freight transport, and other begin to see the response of the consumers and the benefit to the company, perhaps more of those who are involved in the process will also improve their freight management.

Some researchers expect that the increase in overall freight transport will result in a rebalancing of modal share in intermodal domestic freight transport. The projected increase in intermodalism could be driven by a variety of factors, including highway congestion and general improvements

in intermodal facility service operations, and fuel prices (Golob and Regan, 2000; Golob and Regan, 2001; Ballis and Golias, 2002; Shinghal and Fowkes, 2002; Arnold, Peeters et al., 2004; Ballis and Golias, 2004). In addition, increasing environmental pressure stemming from environmentally conscious consumers, professional organizations, private corporations, and government will also encourage more rail and near-coast and inland ship traffic. Even with a balance in the modal share, the final segment of the freight journey, often called the last mile service, will still require the use of trucks but given the growth in door-to-door service this is unavoidable.

A major driver for the GIFT model and an issue that has become increasingly more noticeable are the environmental impacts associated with freight transportation in the United States. As has been noted throughout, freight movement is accompanied by various externalities. The two main externalities associated with freight transport are fuel consumption and air pollution. As the world is currently facing steadily rising fuel costs, many trucking companies are beginning to raise their rates accordingly to adjust for higher fuel costs. The result has been an increase in the cost for many consumer goods. Air pollution associated with freight movement has yet to reach the same level of visibility as fuel consumption, largely because of the complexity and subjectivity associated with defining a monetary value for air pollution.

6.2 Policy Options

There are a range of options available to policymakers to help encourage the use of intermodal transport. There are five major ways that the government can address the environmental externalities associated with the movement of goods. The five ways are:

- Technologically
- Operationally
- Demand-Side Management
- Modal-Shifting
- Alternative Fuels

The GIFT model primarily focuses on one of the ways, which is modal-shifting. But, the model can be used to analyze the impact that all five of the possible approaches could have on the externalities of goods movement. If it is necessary to build the infrastructure to facilitate the seamless transfer of freight, the model can be used to measure the impact of such a facility. If alternative fuels are being used in trucks, the model can be used to determine the impact on air emissions. Operationally, a policymaker can assess the impact of updated infrastructure to transfer freight or encouraging the transfer of freight. It is possible for both to happen simultaneously, but it would be impossible to think of a situation in which one would encourage the transfer of freight if the infrastructure to transfer the freight failed to exist. Therefore, adequate intermodal facilities need to be in place to facilitate the seamless transfer of freight from one mode to another.

There are many issues surrounding the construction of freight transfer facilities. Living near freight facilities, one would find a consistent amount of noise and a higher concentration of pollutants. As a policy maker, one would need to balance not only the needs of the freight transport system, but also societal needs of the community. A way to stimulate the construction of intermodal terminals is to provide tax incentives, subsidies, or grants. By constructing an intermodal facility, jobs would be created and businesses would be more interested in placing their facilities near the freight facility if they knew that by being close to a facility the business would be able to reduce their drayage costs. A second way to encourage the investment would be to ensure that the equipment being used at the site and the practices at the site are as environmentally clean as possible. Understanding that pollutants tend to concentrate in areas near facilities and ports, due diligence should be given to finding ways to transfer freight from mode to mode in the least polluting way. By using the GIFT model, policy and decision makers could weigh these options when considering the construction of an intermodal facility.

If a port or facility is already in place then a decision maker can look at ways to encourage the transfer of freight at the facility. Two major factors determine whether shippers will utilize intermodal terminals. The first is infrastructure. If the infrastructure is inadequate, outdated, or limited in number, this will impact the timeliness and reliability of intermodal transfers. A shipper wants to be able to move their freight quickly and securely. If the transfer of freight from one mode to another takes an extended period of time, the delays will trickle down through

the supply chain from increased congestion at the terminals to possible monetary losses for receivers who may fail to receive their goods on time. The increase in congestion at the terminal will also create an increase in energy consumption and emissions due to idling trucks and machines at the terminal. As noted in Case Study II, freight was being moved from Rochester, NY to Jacksonville, FL and was first moved all of the way to Buffalo, NY in order to transfer to rail. A decision maker can use the model to analyze whether it would be more cost effective for businesses in Rochester to have access to an intermodal facility within the city. If it turns out that the facility would only be used a few times a week, then it certainly would not be cost-effective to construct an intermodal facility.

The second factor impacting the use of intermodal facilities is cost. As a shipper, the goal is to keep your per unit cost down. The cost of transferring freight at a terminal will vary by terminal. Typically, transfer facilities with less expensive transfer costs have aging infrastructure and transfer large amounts of freight on a daily basis. In order to meet the demands of increased freight loads, many facilities have had to update, and in some cases expand, their infrastructure, thereby increasing the cost of transfers to cover the costs associated with updating the infrastructure. The benefit to the shipper would be that these updates would improve the efficiency of the facility by decreasing the amount of time needed to transfer freight allowing the shipper to be able to charge more by being able to have the freight reach its final destination more quickly and securely. The freight industry uses time as their optimizing constraint. This is one reason why congestion has been mentioned more frequently throughout both the public and private sectors. Congestion creates noticeable problems for the freight industry, such as slower average speeds, unreliable travel times, higher fuel and maintenance costs, and increases in accidents and insurance costs (T. Golob and Regan, 2001). Intermodal freight transport can help in many ways to alleviate congestion and help lower costs, but not without an increase in the overall time of delivery and a much more complicated shipping schedule.

To make informed decisions, the policy maker needs to analyze the impact of policy options to identify appropriate trade-offs. There are a variety of policy mechanisms that can be used to help encourage the efficient movement of freight in the US. Taxes and rebates that change the cost structure among transportation modes may help to make up for insufficient government funding for the construction of improvement of intermodal facilities and equipment. Currently,

the market does not fully take into consideration the overwhelming impact that freight movement has on both energy usage, air quality, and the overall impact on infrastructure. An environmental tax may help to provide market correction. Those modes which are less advantageous to the environment would have a higher tax. This may help to make other modes, such as rail and water, more desirable.

Based on the outputs noted in the three case studies, there are a few tax options available that the government could use to help encourage environmentally sustainable freight transport. One can derive, simply by looking at the data, a few suggestions. Imposing a tax on a truck carrier to help offset the externalities caused by truck traffic is a method that could be used to help make sustainable modes of transit more desirable. By looking again at Table 29, which shows the results of a long-haul journey from New York City to Miami, it is easy to see that the least cost route emits nearly five times the amount of CO₂, but costs only \$0.10 less per mile than the least CO₂ route. As a decision maker, one could look at the implementation of a tax of \$0.10 per mile to make up the difference between the least cost and the least CO₂ route. This would create more of a balance between the two routes and encourage shippers and receivers to pursue less energy intensive methods. This type of policy would really impact truck use given that trucking is already one of the most expensive modes of transport. This type of method can be used for any of the variables within the model.

Table 32. Case Study I Results Per Mile

New York City - Miami, FL Route Analysis							
Optimization	CO ₂ (kg/mi)	SO _x (g/mi)	PM ₁₀ (g/mi)	Energy (mmBtu/mi)	Cost (\$/mi)	Time (hr/mi)	Distance (mi)
Min CO2	0.27	0.27	0.18	0.004	0.65	0.04	1432
Min Cost	1.09	3.28	0.98	0.015	0.56	0.04	1185
Min Time	1.01	0.47	0.20	0.011	0.89	0.02	1376

The GIFT model also assists in the development of interesting regulations that can be implemented in order to alleviate the impact that freight movement has on the environment. The

model provides the ability to determine the kilograms of CO₂ emitted per mile for a given route and the kilograms of CO₂ per hour, shown in Table 33.

Table 33. CO₂ distribution

Case Study	kg CO ₂ /mi	kg CO ₂ /hr
Case Study I		
Min CO2	0.27	6.38
Min Cost	1.09	26.37
Min Time	1.01	54.84
Case Study II		
Min CO2	0.26	6.07
Min Cost	0.26	6.07
Min Time	1.00	67.33
Case Study III		
Min CO2	0.26	4.90
Min Cost	1.00	53.21
Min Time	1.00	60.18

The data shown in Table 33 provides a good start to constructing threshold levels of CO₂ for freight hauls. The optimal CO₂ route emits nearly five times less CO₂ per mile than the optimized cost and time routes. It would be possible, using the GIFT model, to determine an appropriate CO₂ per mile threshold for freight companies to stay below. For instance, the kg CO₂ per mile cap could be set at 0.5 kg CO₂ per mile. All freight carriers would need to be sure that their freight journey stayed below this threshold. This type of regulation would also assist in alleviating congestion. If a truck is idling or traveling at low speeds, they tend to produce an increased amount of CO₂ per mile. A kg CO₂ per mile threshold would encourage freight carriers to determine alternative routes that would avoid increased amounts of CO₂ per mile.

Furthermore, it would also be useful to use a kg CO₂ per hour cap. If a truck needed to keep under a certain threshold of CO₂, energy, or other air pollutants, congestion would certainly be

something to avoid. Regulations such as these can be evaluated with the GIFT model. A second approach would be to consider the kg CO₂ per hour for a given freight haul. Although not modeled yet in GIFT, this value would assist in the pursuit of finding the least congested routes in the freight network. The minimum CO₂ in all three of the case studies is significantly lower than the minimum cost and minimum time routes. The advantage is using this value is that the freight carriers and policy analysts will be able to analyze the tradeoffs between CO₂ emissions and the amount of time that the haul takes.

Imposing pollution control technologies and emissions caps might be another policy mechanism that could be utilized. The GIFT model would allow a company to analyze the amount of energy used and emissions from freight shipping on an annual basis. Governments may be able to implement an annual energy or CO₂ threshold. This would encourage the use of more efficient means of transport and also create a market for emissions credits. Companies that stay below their threshold may be able to sell those extra credits to companies that are unable to stay below the threshold, thereby creating a competitive market for intermodal transport. Other types of regulations can be implemented and evaluated using the GIFT model.

There are other pieces of infrastructure, other than intermodal facilities and ports, which need increased attention. A primary concern for the Federal Railway Administration is the condition of many of tracks in the United States. The tracks are old and need to be updated to ensure quality and safety. Another part of the freight transport infrastructure is the national highway system. The system is growing older, more congested, and in dire need of repair. One of the strategies currently used by the government is to increase the capacity of the highway system by constructing new highways, creating more lanes, and continuously maintaining the highway infrastructure. This type of strategy comes at a considerable cost, with new highway construction approaching nearly \$30 million dollars per lane mile and interchanges costing nearly \$100 million (Lombardo et al., 2004). Due to recent events, bridge safety has become another important concern and many have learned that the bridges are also in need of repair and this is yet another cost.

The education of users and consumers about the overall impact of the use of infrastructure and its impact on society is important. In order to pay for the updates in the freight transport system

infrastructure, much of that money would need to come from taxes or usage fees. Taxes can be placed on the use of the infrastructure, the goods being moved, or a form of state or local tax. Fees could be placed on users of the infrastructure, and this usage fee would typically be paid by the receiver (consumer) of the good. In order to provide the public an explanation as to why these taxes are necessary, the education of the freight transport system is necessary. Given that the current market structure fails to incorporate much of the operation and maintenance funds necessary, government needs to impose a tax in order to close the gap within the market. The education of the users and consumers may encourage some to adjust their choices to incorporate more environmental consideration.

The proposals discussed above will be very difficult to set in motion without some adjustments to agency budgets. The FY 2008 budget has allocated, at the agency level, \$37.2 billion to the Federal Highway Administration, \$1.1 billion to the Federal Railway Administration, and \$295 million to the Maritime Administration.⁶ The funding allocated to each of the agencies closely reflects the usage of the modes, with the agency with the higher amount of funding being the most used mode of freight transport. In order to create a balance between the three modes of transport, there needs to be more of a balance when it comes to funding for the agencies which represent those modes. If the budget structure maintains the same course, it will be increasingly difficult for rail and waterway transport to build up their infrastructure so that they can be comparable to the highway system.

7. Conclusion

By leveraging the capabilities of the ArcGIS software the GIFT model was able to quickly provide a functional policy analyst decision support tool. The addition of custom evaluators allowed for the computation of data to assess the environmental impact of intermodal freight transportation. The user interface brought the entire project full circle by allowing the useful interaction between the policy analyst/decision maker and the model to set up and analyze policy options and their impacts. The ability to explore tradeoffs and policy alternatives is what makes the GIFT model very unique. As has been previously noted, many of the models that had been previously constructed failed to connect the operating cost attributes with the energy and

⁶ <http://www.whitehouse.gov/omb/budget/fy2008/transportation.html>

emissions attributes. The GIFT model not only combines the different attributes, but allows for the tradeoffs between them.

As with any model, there are areas of improvement to be noted. Acquiring quality freight data are certainly a major goal for future generations of the GIFT model. The current data from NTAD serves its purpose but has many glitches, such as locating intermodal transfer facilities by mailing address and not by physical transfer location. Also, the NTAD has two datasets that are used in the intermodal network creation, facilities and ports. Often, ports will be located in the facility dataset and vice versa. Further data considerations are to acquire accurate speed limit data for all segments in the model and obtain a more comprehensive waterway network. These data problems currently limit the robustness of the GIFT model.

The cost data of the GIFT model are also another area that needs further consideration. These data used in the model were acquired from multiple sources over a varying amount of time. In order to construct a solid base case for the GIFT model, further consideration needs to be given to obtaining comprehensive cost data for both the segments in the model and the transfers. In order to have accurate route selection, the metadata for the datasets that are chosen needs to be accurate and comprehensive. Currently, when one looks at the directions, they will see segments without names or distances. These types of problems need to be addressed in future generations of the model.

Another area of improvement focuses on the intermodal network. The current model is built in a triangle, as shown in Figure 9, connecting the different transport modes together one by one. A more efficient method that has been proposed would use a hub-and-spoke linking method, thereby fully integrating the transfer points into the intermodal network. This method would create a more realistic network with costs being borne not just on the links but also at the transfer facilities. The hub-and-spoke network is also able to be created much more efficiently using many of the tools available within ArcView. The ability to automate the intermodal network creation process would be a great advancement for the GIFT project.

A number of advancements are also proposed for the visual interface and analysis tools available with the GIFT model. Requirements have been identified and proposals have been drafted for an

improved user interface which will cater to the needs of decision makers and policy analysts. A policy maker needs to have an intuitive display of their policy scenario with clear cost factors and results. Additionally, policy analysts need to have the ability to visualize and compare results from different scenarios, the ability to save and restore scenarios, and the ability to generate reports for analysis.

Another change being pursued is moving the network analysis from the desktop to a web server. Currently, the system is implemented on ArcGIS Desktop 9.1. With the release of ArcServer 9.2 comes the ability to do network analysis on a server and make that available to policy analysts via a web browser. This transition will save analysts the cost and difficulty of needing to have ArcGIS installed on their personal computers, and it will ease overall maintenance by eliminating the need to have to install or update new software on all of the computers that would be using the model.

Further enhancements for future generations of the GIFT model include the integration of real-time and predicted congestion and capacity models to reflect the increased shipping traffic and the resulting energy and emissions on congested highways, railways, and ports. By adding congestion and capacity to the model, an analyst will be able to create more of an economy of scale with the model by looking at large-scale shipments rather than per container. Capacity models can enable policy analysts to conduct more comprehensive scenario analysis for infrastructure improvement or degradation (such as after a disaster), including new truck/train transfer facilities, new or improved ports, new or improved highways, or improved ship and barge canal locks. The integration of dispersion models would provide another dimension to the model. Not only would a policy analyst be able to understand the energy usage and emissions from freight transport, they would also be able to determine what happens to the emissions once they have entered the air. This type of analysis would be able to draw a connection, if one exists, between freight transport activities and human health. This type of information would further influence future governmental policy decisions.

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